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NUTRIENT REMOVAL FROM CANNERY WASTES BY SPRAY IRRIGATION OF GRASSLAND

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NUTRIENT REMOVAL FROM CANNERY WASTES BY SPRAY IRRIGATION OF GRASSLAND

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FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

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TABLE OF CONTENTS

		Page
PREFACE		iii
LIST OF TABLES		vii
LIST OF FIGURES		ix
SUMMARY		xi
Chapter		
I.	INTRODUCTION	1
II.	EXPERIMENTAL PLAN	5
III.	WASTEWATER CHARACTERIZATION	9
IV.	HYDROLOGY	17
V.	WATERSHED TREATMENT EFFICIENCIES	25
VI.	FARM EFFLUENT QUALITY	37
VII.	SOIL AND SOIL WATER	47
VIII.	SUPPLEMENTAL STUDIES	53
REFERENCES		63
APPENDIX I	Description of Chemical Parameters	67
APPENDIX II	Chemical Data Form for Surface Water Samples	71
APPENDIX III	Chemical Data Form for Soil Water Samples	73

PREFACE

This study was part of a joint venture with the Campbell Soup Company which sponsored investigations by C. W. Thornthwaite Associates of climatological and agricultural phases along with sponsorship of North Texas State University's evaluations of biological relationships.

A compendium of all the efforts of the various researchers is available in Publications in Climatology, Volume 22, #2, Laboratory of Climatology, Elmer, New Jersey. The major contributors to the research effort in other areas were D. M. Parmelee and J. P. Ford of C. W. Thornthwaite Associates and A. S. Kester and J. P. Vela, Biology Department, North Texas State University.

The authors wish to acknowledge the cooperation and assistance of Mr. L. C. Gilde, Director-Environmental Engineering, Campbell Soup Company, Camden, New Jersey, and Mr. Charles Neeley and his associates at the Paris, Texas, plant. Their cooperation made the conduct of this study possible and their detailed knowledge of the system and its operation made the task much easier for all participants.

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LIST OF TABLES

Table		Page
1.	Description of Experimental Watersheds	6
2.	Spray Application Schedule for the Experimental Watersheds	7
3.	Characteristics of Wastewater at the Four Experimental Spray Lines from April 1968 Through October 1968	10
4.	Wastewater Composition Change During Collection and Handling	11
5.	Daily Variation in Composition of Wastewater	14
6.	Wastewater Characteristics, Means for All Sampling Periods	15
7.	Deviation of Rainfall and Evaporation from Normal	19
8.	Seasonal Water Balances	21
9.	Percent Distribution of Water Accounted for on the Four Experimental Watersheds	22
10.	Mean Chemical Quality of Runoff and Concentration Treatment Efficiency for Watershed G-4	27
11.	Mean Chemical Quality of Runoff and Concentration Treatment Efficiency for Watershed G-11	28
12.	Mean Chemical Quality of Runoff and Concentration Treatment Efficiency for Watershed B-11	29
13.	Mean Chemical Quality of Runoff and Concentration Treatment Efficiency for Watershed Y-1	30
14.	Mean Mass Removal Percentages from April 1968 Through October 1968	33
15.	Mean Mass Removal Percentages from November 1968 Through April 1969	34
16.	Farm Effluent Quality and Concentration Treatment Efficiency, Mean Values	45
17.	Soil Sample Analyses	48
18.	Summary of Soil Water Analyses	51
19.	Treatment Efficiency Versus Distance Downslope from Spray Line	54
20.	Contaminants Removed by Filtration	55
21.	Nitrate in Fixed and Unfixed Wastewater Samples	57

LIST OF TABLES

Table | Page

22. Recovery of Treatment Efficiency by Resting a Watershed. 58

23. Mean Concentration of Rainfall Runoff and Subsequent Wastewater-Spray Runoff from the Experimental Watersheds. 61

LIST OF FIGURES

Figure		Page
1.	Diurnal Variation in Composition of Wastewater. . . .	13
2.	Effect of Rainfall on the Fraction of Liquid Recovered as Runoff.	24
3.	Daily Mean Electrical Conductivities.	39
4.	Effect of Rainfall on Electrical Conductivity of Farm Effluent	41
5.	Diurnal Variation of Electrical Conductivity of Wastewater.	43
6.	Diurnal Variation of Electrical Conductivity of Farm Effluent.	44
7.	Changes of Nitrate and Nitrite Concentrations with Time in Unfixed Wastewater Samples.	56
8.	Effect of Extended Drying on Nitrogen Transformations and Percent Removal	60

SUMMARY

A comprehensive 12-month study was conducted to determine treatment efficiencies of a spray-runoff system for cannery wastes. A total of 133 inches of wastewater was applied to four experimental watersheds during the study period. Hydrological measurements, chemical removal efficiencies, and changes in soil properties were evaluated in relation to years of wastewater application, soil type, and spray schedule.

Hydrological measurements were made to account for all liquid applied and lost from the experimental watersheds. The measurement techniques employed accounted for 93 percent of the applied liquid during the 12-month study. Water balances showed that evaporative losses accounted for 18 percent of the total liquid applied, runoff accounted for 61 percent, and deep-soil percolation accounted for 21 percent. Runoff from the clay loam soil was measurably greater than from the sandy loam soil. During periods of heavy rainfall, runoff increased to a maximum of 80 percent of the total applied liquid.

The wastewater quality varied regularly according to routine changes in the production schedule. The spray-runoff system provided a buffering capacity, which eliminated most of this variability from the quality of the stream leaving the system. Rainfall provided dilution water and removed stored soluble salts at low concentrations during periods of high flow.

The results of this study showed that a high degree of treatment was achieved. Under its present operating schedule, the system achieves mass removals of 92 to 99 percent of the volatile solids and oxygen-demanding substances, 86 to 93 percent removal of nitrogen, and 50 to 65 percent removal of phosphorus. Mass removal efficiencies were consistently greater than concentration reduction efficiencies since the runoff ranged from 40 to 80 percent of the applied wastewater. Soil textural class and system age had very little effect on treatment efficiencies.

Although the present system design and operating schedule provide excellent treatment, the results of this study showed that treatment efficiency was improved by spreading the wastewater load over a greater fraction of the land area and by reducing the frequency of application. The greatest change was in phosphorus removal, which was increased from 40 percent to 88 percent by changing from a one-per-day to three-per-week spray schedule. Data from three farm effluent locations verified the ability of the spray-runoff system to produce a highly treated effluent throughout the year, although there appeared to be a slight reduction in efficiency during the winter months.

Evaluation of surface and subsoil samples and soil water samples collected monthly at the 3-foot depth indicated an increase in salinity with age. Both total dissolved solids and sodium showed increases on the older watersheds, but nitrogen and phosphorus remained low. A substantial fraction of the phosphorus removed from the wastewater was accounted for in the surface soil layer. The buildup of salinity and sodium on the older watersheds indicates that these should be monitored again in a few years to determine if a state of equilibrium were being reached. If they should continue to increase, soil and plant problems could develop at sometime in the future.

CHAPTER I

INTRODUCTION

The spray application of waste effluents to soil-plant systems as a treatment method has received increased attention in the past decade (1). It has been applied to such diverse industrial wastes as those from paper mills and canneries as well as municipal sewage treatment plant effluents (2,3,4,5,6). For treatment efficiency, such a system relies not only on infiltration and plant utilization but, in some cases, a rather large percentage of the applied liquid receives treatment and returns as surface runoff. Crop production is not usually the primary objective of such waste treatment systems. However, a recent report (7) showed that cash crop production over an 8-year period was excellent with no apparent damage to crops or soil when irrigated regularly with a paper mill waste effluent. Applications have been made on areas ranging from forested to grassland, and the systems have been referred to as grass filters and "living filters" (8).

A spray-runoff soil treatment system for cannery wastes was designed for the Campbell Soup Company plant at Paris, Texas, by C. W. Thornthwaite Associates of Elmer, New Jersey, and put into operation late in 1964 (9). The initial system of about 250 acres was expanded to about 400 acres in 1965 to accommodate an increase in wastewater flow. Through 1965, plant production increased to a waste output level of 2.2 million gallons per day (MGD). With the additional farm area, waste output reached about 3.2 MGD in 1968. This soil system receives the wastewater from the production of the complete line of heat process soups.

Prior to levelling, terracing, and preparing for the present system, the land was severely eroded from cotton farming during the 1930's and had been abandoned to native vegetation. Extensive levelling obscured the remaining thin layer of topsoil and exposed the gray to reddish clay subsoil in much of the area.

Terraces and the intervening spray lines were located 200 to 300 feet apart on slopes ranging from 1 to 6 percent. There are over 700 sprinklers on 77 individual spray lines that are semi-automatically controlled by clock mechanisms. The spray lines operate on a 24-hour basis--6 hours on, 18 hours off during cool humid winter months; and 8 hours on, 16 hours off during late spring, summer, and early fall. The slopes are covered with a lush growth of Reed canarygrass, tall fescue, and red top. Reed canarygrass predominates in the spray pattern and downslope in the wettest areas. The other two varieties cover the remainder of the slopes with some native bermuda persisting in limited areas.

During the first few years of operation, the grasses were mowed and the litter left on the fields to decompose and build up an organic layer. A partial harvest of hay was removed in 1967 and in 1968 the entire area was harvested once.

Our interest in a research study of the system was inspired by a visit to the plant in May 1967. At that time it was learned that the 5-day biochemical oxygen demand (BOD) test was the principal parameter used to judge the treatment efficiency of the system. It was also learned that the untreated waste had a BOD content of 500-800 mg/l, while the BOD of the runoff was consistently less than 10 mg/l. The pH of the waste fluctuated daily from a low of about 5 during raw material preparation and product processing to a high of about 10 at night when kettle washing and plant cleaning operations were in progress.

Although all phases of the treatment system satisfied the requirements of the State Health Department, there remained many unanswered questions regarding the efficiency of the system from a pollution control viewpoint. No doubt the organic content was successfully removed. No data were available relating to the total nitrogen and phosphorus content of the waste or the runoff. The question was raised as to whether the BOD test alone was an

adequate criterion for judging the success of the operation. No measurements of the runoff volume had ever been made, but it was estimated to be as low as 20 percent in the hot summer months and 80 percent or higher during humid winter weather.

Further observations in the fields revealed a tough organic layer on the soil surface within the sprinkler areas. It appeared that such an organic layer would greatly reduce infiltration in those areas, since it could be peeled from the soil showing very little penetration of the surface. In areas where it had dried, it tended to crack and curl, exposing the soil underneath. Interesting questions were raised regarding the role of this organic layer in the treatment process. Does it act similarly to the slime coating of a trickling filter? The following additional questions formed the basis for conducting a detailed study of the treatment system:

a. What is the treatment efficiency with regard to the nutrient compounds of nitrogen and phosphorus?
b. How does the treatment efficiency vary with a range of loading and runoff conditions?
c. How much runoff actually occurs and how does it vary with the seasons?
d. What is the character, quantity, and fate of the percolating soil water?
e. How does the soil moisture profile vary with loading?
f. What range of salinity is encountered in the waste and runoff?
g. What is the effect of a wide range in pH on soil plants?
h. What is the sodium content of the waste, and what long-term effects on the soil may be expected?
i. Should the grass be harvested and removed or left on the fields to decompose?
j. Does the present spray schedule constitute the optimum loading rate?

Objectives of the Study

Subsequent discussions with company officials revealed their interest and willingness to permit a 12-month detailed study of the treatment system. Plans were formulated for this proposed study with the following specific research objectives:

a. To determine the nutrient removal efficiency of spray irrigation of grassland as it is presently being practiced at the Campbell Soup Company plant, Paris, Texas.

b. To determine infiltration, surface runoff, and soil moisture fluctuations under different loading conditions.

c. To correlate nutrient removal efficiency to presently observed reduction in BOD and suspended solids.

d. To more fully elucidate the mechanisms responsible for treatment efficiencies observed in the spray irrigation "grass filter" type of waste treatment system.

Our research plan was approved and made a part of a comprehensive study involving four organizations. Campbell Soup Company coordinated the three-phase research study and financed the microbiological, microclimatological, and crop management research conducted by the Biology Department of North Texas State University and C. W. Thornthwaite Associates. The Robert S. Kerr Water Research Center conducted a concurrent and independent study to evaluate the hydrology and treatment efficiency of the system. This report presents the results of the treatment efficiency data collected during the 12-month detailed study of the spray-runoff treatment system.

CHAPTER II

EXPERIMENTAL PLAN

A 12-month experimental period was selected to provide an evaluation of the system under the climatic conditions for all four seasons. Several existing watersheds which were representative of the whole system were selected for experimental study. These watersheds were instrumented to provide a continuous record of the hydrology, the quality of the applied wastewater, and the quality of the water leaving the treatment system.

The four watersheds were selected to represent the known differences in date of establishment and soil textural class. Descriptions of the four experimental watersheds are summarized in Table 1. These watersheds were isolated so that the only liquid reaching them was natural rainfall or wastewater spray actually falling within the watershed. Isolation was accomplished by modifying existing terraces, taking advantage of natural divides, and forming boundaries with lawn edging. Composite soil samples, obtained from 15 subsamples, were taken to determine the effects of wastewater spraying on the soil. Samples at the 0- to 2-inch and 11- to 13-inch depths were taken from the experimental area receiving wastewater and from the border area not receiving wastewater.

Spray applications to these four watersheds were continued on the same schedule as the rest of the treatment system except for two minor changes. One change insured that each experimental area received continuous application throughout each scheduled spray period, whereas the normal spray schedule permitted intermittent spraying during some of the scheduled spray periods. The other change was to program the experimental areas out of weekend operation while the normal schedule called for weekend operation once every three or four weeks. The spray application schedule for the four experimental watersheds is presented in Table 2. The periods when no spray was applied were times when the plant was shut down, when crops were being harvested, or when a line needed a rest

TABLE 1

DESCRIPTION OF EXPERIMENTAL WATERSHEDS

Identification Code	Year Spray Started	Area (Acres)	Slope		Soil Textural Class	
			Percent	Length (ft)	0- to 2-inch depth	11- to 13-inch depth
G-4	1964	3.9	2-3	320	sandy loam	sandy clay loam
Y-1	1964	2.6	2	280	clay loam	clay
G-11	1966	1.5	4-6	150-280	sandy loam	sandy clay loam
B-11	1966	3.4	2	220	loam	clay

TABLE 2

SPRAY APPLICATION SCHEDULE FOR THE EXPERIMENTAL WATERSHEDS

G-4		Y-1	
Dates	Spray (in./week)	Dates	Spray (in./week)
4/22/68 - 6/1/68	3.8	4/22/68 - 6/1/68	4.4
6/2/68 - 7/29/68	5.1	6/2/68 - 7/22/68	6.0
7/30/68 - 8/24/68	0.0	7/22/68 - 8/18/68	0.0
8/25/68 - 9/25/68	6.2	8/19/68 - 9/25/68	7.1
9/26/68 - 10/7/68	0.0	9/26/68 - 10/7/68	0.0
10/8/68 - 10/31/68	4.5	10/8/68 - 10/31/68	5.2
11/1/68 - 4/25/69	3.2	11/1/68 - 2/24/69	3.1
		2/25/69 - 3/7/69	0.0
		3/8/69 - 4/25/69	3.1

G-11		B-11	
Dates	Spray (in./week)	Dates	Spray (in./week)
4/22/68 - 6/1/68	3.8	4/22/68 - 5/6/68	3.2
6/2/68 - 7/29/68	5.1	5/7/68 - 6/22/68	0.0
7/30/68 - 8/24/68	0.0	6/23/68 - 8/24/68	4.3
8/25/68 - 9/25/68	6.2	8/25/68 - 9/25/68	5.1
9/26/68 - 10/7/68	0.0	9/26/68 - 10/7/68	0.0
10/8/68 - 10/31/68	4.5	10/8/68 - 10/31/68	3.8
11/1/68 - 2/20/69	3.8	11/1/68 - 4/16/69	3.5
2/20/69 - 3/1/69	0.0	4/16/69 - 4/25/69	0.0
3/2/69 - 4/25/69	3.8		

to recover its ability to treat the wastewater. The variation in the amount of spray scheduled for application was the result of seasonal operating changes, watershed characteristics, and changes in plant production requirements. During the 12-month study period, the experimental areas averaged 43 weeks of spray application and received an average of 133 inches of wastewater.

Volume measurements of the liquid applied and the water losses from the experimental area were determined to make a complete water balance. Rainfall and spray were the only sources of applied liquid, and the loss of liquid was attributed to spray evaporation, evapotranspiration, runoff, and soil percolation. Rainfall was measured with rain gauges; wastewater spray volumes were calculated from nozzle delivery rates and time information; spray evaporation was determined empirically; evapotranspiration was calculated from weather data collected at an on-site weather station; runoff was determined with flow measuring flumes; and soil percolation was estimated from changes in the soil moisture content following spray applications.

Four sampling points were selected for monitoring the changes in the quality of the wastewater as it was treated. These points were the wastewater spray line, the runoff flume, the stream leaving the treatment system, and the soil water at the 3-foot depth. Abrupt changes in the quality of the wastewater being applied and design characteristics of the wastewater treatment system made it necessary to use special care in obtaining representative liquid samples. Fifteen chemical parameters were used to evaluate the quality of the liquid samples.

Detailed explanations of the experimental procedures and special instrumentation employed are included in the appropriate sections which follow.

CHAPTER III

WASTEWATER CHARACTERIZATION

Methods and Procedures

Determination of changes in concentration of all chemical parameters studied was dependent on establishing the composition of the wastewater for each sampling period. Wastewater samples were collected in the spray pattern of each experimental line by using three powder funnel-and-jug arrangements. The jugs were supported on metal stands above the vegetation and were spaced equidistant along the spray lines. At each spray line, one jug was placed near a nozzle, one midway of the spray pattern, and one near the outer edge of the pattern. At the completion of a spray period, the wastewater sample was taken by compositing a one-gallon sample from the three collecting jugs. Fifteen chemical parameters were used to characterize the wastewater. The analytical procedures used were the Official Interim Methods of the Federal Water Pollution Control Administration (10). Descriptions of the chemical parameters, abbreviations used, and sample analytical data forms are included in Appendices I, II, and III.

Results and Discussion

During the first six months of the study, wastewater samples were collected at each of the four experimental lines to determine the variability in composition. The results of this evaluation of five parameters are presented in Table 3. Statistical analyses of these data indicated that there were no significant differences in the composition of the wastewater spray collected at the four experimental lines. Therefore, the wastewater sampling procedure was modified to reduce the number of individual samples. From November 1968 through April 1969, composite wastewater samples were obtained from lines G-4 and G-11.

TABLE 3

CHARACTERISTICS OF WASTEWATER AT THE FOUR EXPERIMENTAL SPRAY LINES FROM APRIL 1968 THROUGH OCTOBER 1968

Spray line	Concentration, mg/l				
	BOD	COD	VSS	T-P	T-N
G-4	467	721	179	8.4	18.8
Y-1	486	697	174	8.4	17.1
G-11	516	762	183	8.6	18.8
B-11	451	759	189	9.0	21.2

Note: Abbreviations of chemical parameters are explained in Appendix I.

The method of collecting and handling wastewater samples provided both time and conditions suitable for some loss of biodegradable constituents before analysis. The extent of this loss was evaluated during the latter six months of the study. This was accomplished by simultaneously collecting two sets of wastewater samples on each of the two experimental lines, G-4 and G-11. One set was collected in bottles containing concentrated sulfuric acid to immediately fix the sample and stop all biological activity. The other set was collected and nandled in the normal manner. The results of this comparison for four parameters are presented in Table 4. The concentrations of the major organic parameters in the acid-fixed samples were consistently greater than those in the unfixed samples. The indicated losses ranged from a low of 4 percent for phosphorus to a high of 12 percent for total nitrogen. A statistical analysis of the data showed that the differences in the concentration for COD and TOC were significantly different at the 5 percent level of probability,

TABLE 4

WASTEWATER COMPOSITION CHANGE DURING COLLECTION AND HANDLING

Method of Sample Collection	Concentration, mg/l			
	COD	TOC	T-P	T-N
Non-fixed	1010	300	6.7	19.2
Fixed	1140	340	7.0	21.7

Note: Abbreviations of chemical parameters are explained in Appendix I.

while the differences for total phosphorus and total nitrogen were not. It is apparent that the composition of the wastewater changed somewhat during the normal sampling and handling procedure. However, this change in composition of the wastewater does not detract from the validity of the treatment efficiencies reported, since it represents a small negative effect on the calculated values.

Variability in composition. The major source of variability in wastewater composition was the diurnal changes associated with the schedule of operations in the processing plant. Raw vegetable processing began about 0500 each workday and continued until mid-afternoon. Workers arriving at 0700 began preparing the raw products for cooking and canning the assigned batches of finished products for the day's production. The late evening-to-midnight shift completed the cooking and canning operations. Workers arriving at midnight carried out the major cleanup operations for the day, washing down cooking kettles, all processing machinery, processing plant floors, etc., all in preparation for the next day's operations. Thus, the operations being performed in the processing plant at different periods of the

day had an influence on the wastewater characteristics. The diurnal variation in wastewater composition is summarized in Figure 1.

BOD, COD, and VSS exhibited very similar patterns of variation. Minimum concentrations occurred during the early morning cleanup period and maximum concentrations occurred during daytime and evening when the major operations were processing and canning. Phosphorus concentrations were greatest during the plant cleanup operation. Changes in the nitrogen concentration were relatively minor and did not follow the pattern of any of the other parameters. Phosphorus showed the greatest range of variability, ranging from a high mean of 16.8 mg/l during cleanup to a low mean of 3.1 mg/l during processing and canning.

Four times during the 12-month study, intensive study periods of one week each were conducted. These were scheduled at 3-month intervals so that all seasons were represented. The daily variation in the composition for these intensive study periods is shown in Table 5. There were large day-to-day changes in the composition of the wastewater during each of the four seasonal sampling periods. The daily changes in composition occurred randomly, and there was no consistent pattern to wastewater composition changes during the week.

A complete summary of wastewater characteristics is presented in Table 6. The four 6-hour sampling periods represent the October through May spray schedule, and the three 8-hour sampling periods represent the June through September spray schedule. The 24-hour composite was obtained by taking a weighted average of the data collected for the seven time intervals.

Summary and Conclusions

The sampling procedures used to characterize the wastewater established many factors pertinent to evaluating the nutrient removal efficiency of the treatment system. The hypothesis that the wastewater quality would be variable was substantiated.

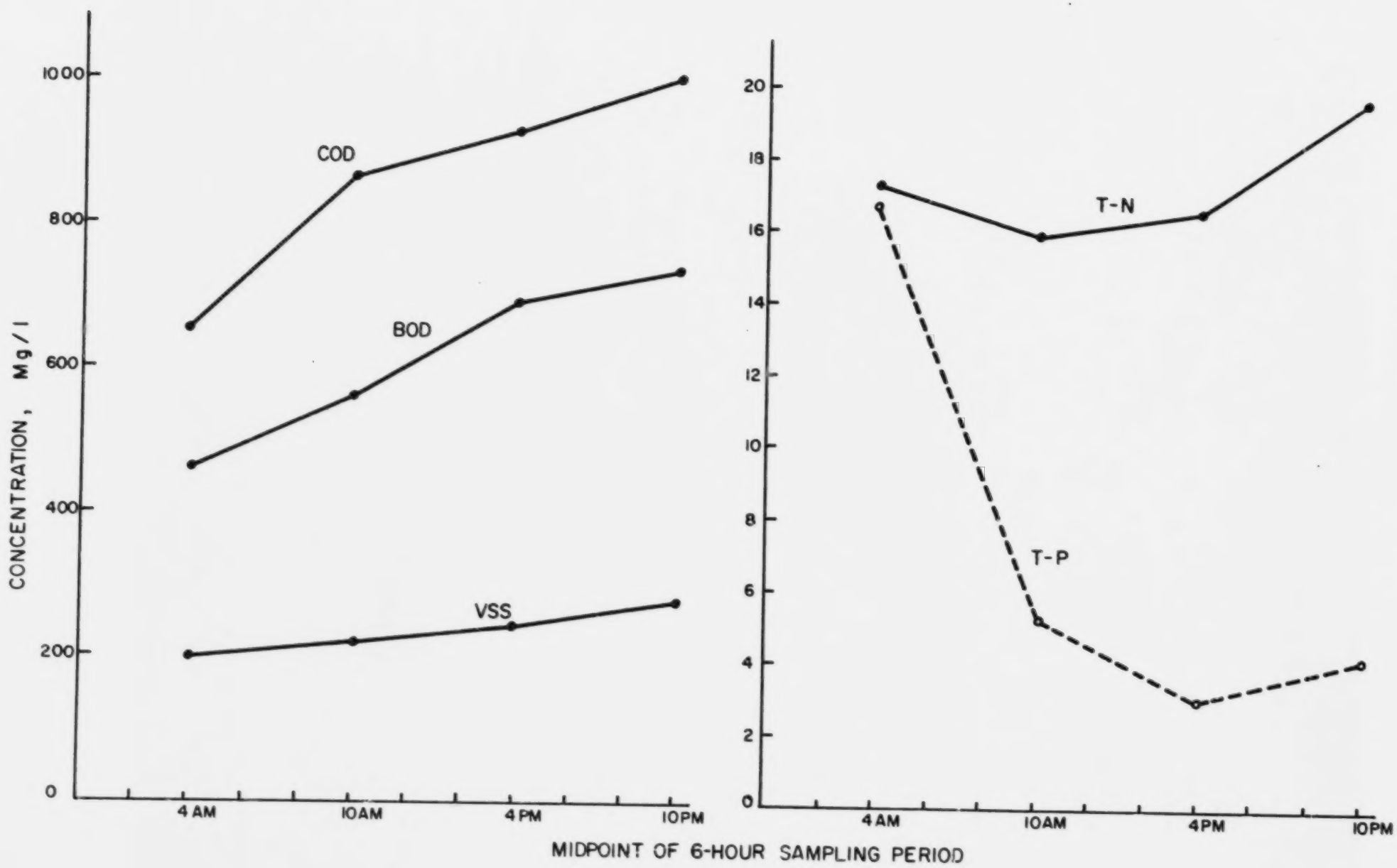

FIGURE I - DIURNAL VARIATION IN COMPOSITION OF WASTEWATER

TABLE 5

DAILY VARIATION IN COMPOSITION OF WASTEWATER

Season	Monday	Tuesday	Wednesday	Thursday
		BOD, mg/l		
Summer	---	646	593	700
Fall	517	506	483	590
Winter	663	556	341	557
Spring	521	578	425	596
		COD, mg/l		
Summer	734	872	802	1030
Fall	590	708	718	863
Winter	1040	944	664	577
Spring	1040	1012	871	1055
		VSS, mg/l		
Summer	116	193	203	---
Fall	279	242	112	181
Winter	202	270	128	232
Spring	---	248	240	288
		T-P, mg/l		
Summer	3.4	4.0	3.5	3.1
Fall	1.5	4.8	4.6	3.6
Winter	4.5	4.2	2.5	4.0
Spring	4.7	4.6	3.6	3.2
		T-N, mg/l		
Summer	16.5	20.8	23.6	25.6
Fall	6.5	9.5	9.9	10.9
Winter	36.1	26.8	12.1	21.5
Spring	22.5	30.5	16.8	21.8

Note: Abbreviations of chemical parameters are explained in Appendix I.

TABLE 6

WASTEWATER CHARACTERISTICS, MEANS FOR ALL SAMPLING PERIODS[a]

Parameter	Time interval for collecting composite samples							24-hour Composite
	1 a.m.-7 a.m.	7 a.m.-1 p.m.	1 p.m.-7 p.m.	7 p.m.-1 a.m.	7 a.m.-3 p.m.	3 p.m.-11 p.m.	11 p.m.-7 a.m.	
pH, units[b]	8.2	6.6	6.9	6.6	6.0	4.8	6.6	6.6
EC, µmhos/cm	490	420	400	430	480	450	500	450
Cl	58	40	38	39	36	38	54	44
M.O. Alk	106	60	80	42	35	18	93	68
TSS	230	246	267	305	226	211	166	245
VSS	201	219	245	277	206	162	148	218
TP	16.7	5.2	3.0	4.1	3.3	3.8	11.7	7.4
NO_3-N	0.4	0.2	0.2	0.2	0.1	0.1	0.1	0.2
NO_2-N	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
NH_3-N	---	---	---	---	---	---	---	1.0
Kjeldl-N	16.9	15.7	16.3	19.4	14.7	16.8	17.2	17.0
Total-N	17.3	15.9	16.5	19.6	14.8	16.9	17.3	17.2
COD	655	869	925	1005	697	667	629	806
TOC	198	284	282	300	211	234	194	250
BOD	463	562	693	737	494	476	409	572

[a] All concentrations in mg/l except where noted
[b] Median values instead of a mean

Note: Abbreviations of chemical parameters are explained in Appendix I.

Much of the variability was shown to be related to changes in the plant operation. It was shown that there was no measurable difference in the quality of wastewater delivered to the four experimental watersheds, therefore, differences in the composition of the wastewater would not bias the comparison of treatment efficiencies between watersheds. The sample collection and handling procedure allowed a measurable loss of oxygen demand of about 10 percent. This loss had little effect on the percent removal of oxygen demand because the removals were in the 95 to 99 percent range. There were no composition changes related to the day of the week so the Wednesday samples used throughout the 12-month study were taken to be indicative of operations on any day of the week.

CHAPTER IV

HYDROLOGY

The evaluation of the system's hydrology depended on identifying and accurately measuring the effects of the processes which contributed or withdrew liquid from the experimental watersheds. Selection and isolation of the watersheds limited the contributing processes to rainfall and wastewater spray. Spray evaporation, evapotranspiration, runoff, and soil percolation were selected as the withdrawal processes which would contribute measurably to the total water loss. The method chosen for measuring each of these six parameters is discussed briefly and an estimate of the reliability of the method is given.

Methods and Procedures

A network of three rain gauges provided an accurate record of rainfall data, and no difficulties were experienced in determining this fraction of the liquid load with a high degree of accuracy. The spray volume was calculated from nozzle delivery rates and time data. Occasional mechanical malfunctions such as nozzle plugging, valve failures, pressure variations, and spray line leaks caused discrepancies in the determination of spray volumes. A routine practice of reporting operational procedures and problems was used to eliminate most of the data influenced in this manner. Evaluation of the characteristics of runoff peaks provided a final check on the volume of spray. Persistent mechanical leaks of less than 5 percent of the daily spray volume were detected with these cross-checking procedures. The reliability of the determination for wastewater spray was about ±10 percent.

The initial liquid loss was direct evaporation of the spray before it reached the ground. This loss has been reported to range from 2 to 8 percent (11). An empirical method was chosen to estimate this relatively small component of the total water

loss. The empirical method was based on an arbitrarily derived relationship between the 2- to 8-percent range, the time of day, and evapotranspiration values.

Evapotranspiration was calculated from the weather observations taken at the on-site weather station. Daily values were calculated by the Thornthwaite and Mather method (12). These values were subsequently recalculated to correct for seasonal discrepancies which are inherent in this method.[1] A reliability range of ±22 percent is generally accepted as good for estimates of potential evapotranspiration (13).

Runoff was measured with the H-flume developed by the U. S. Department of Agriculture (14). This flume was selected because of its high accuracy over a wide range of flow rates. The flumes installed had a working range of 0.001 to 5.33 cfs. This range provided very accurate measurement for the low runoff rates following summer spray applications as well as the high runoff rates from high intensity rain showers.

A neutron soil moisture logger was used to obtain data for estimating soil percolation. The instrument used produced very accurate soil moisture profiles at a logging speed of 2.5 feet per minute. The method of Rose, Stern, and Drummond (15) was used to calculate deep soil percolation from a series of soil moisture profiles and soil-water suction data. Such estimates of deep soil percolation have a reliability of about ±25 percent (16).

Results and Discussion

Liquid applied. The rainfall and evaporation data presented in Table 7 show that climatic conditions during the 12-month study deviated considerably from normal. Rainfall at the experimental site was 57.00 inches for the study period. This exceeded the normal for the official weather station at Paris, Texas, by 11.89 inches. The nearest weather station

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[1]Personal communication with J. R. Mather, C. W. Thornthwaite Associates, Elmer, New Jersey, February 1969.

TABLE 7

DEVIATION OF RAINFALL AND EVAPORATION FROM NORMAL

Month	Deviation, inches	
	Rainfall[a]	Evaporation[b]
1968 May	+0.21	-1.50
June	+1.57	-2.15
July	+0.66	-2.09
August	-1.95	-0.73
September	+4.47	-1.24
October	+0.34	-0.06
November	+2.50	-0.43
December	-0.64	+0.28
1969 January	+3.15	-0.18
February	+2.07	-0.37
March	+1.77	-1.04
April	-2.26	-1.14

[a]Rainfall deviation is from normals for Weather Bureau Station at Paris, Texas.

[b]Evaporation deviation is from normals for Weather Bureau Class A Pan at Denison Dam which is 65 miles west of Paris, Texas.

measuring evaporation was at Denison Dam, which is 65 miles west of the experimental area. The evaporation at this station was 10.65 inches below normal for the 12 months of the study. These weather conditions increased rainfall as a fraction of the liquid applied and increased runoff in comparison to results for normal or droughty weather conditions. The applied liquid for the study period was 24 percent rainfall and 76 percent wastewater spray. In a year with the same amount of wastewater spray and rainfall 10 inches below normal, rainfall would account for only 16 percent of the total applied liquid.

Water balance. The major objective of the hydrology study was to obtain a complete water balance for each of the experimental watersheds so that nutrient removal efficiences could be evaluated on a mass basis. These water balances are summarized in Table 8. These data showed that similar balances were achieved for each of the watersheds under all operating conditions. Each water balance was best in the spring and poorest in winter with the fall and summer values intermediate. The overall water balances ranged from 91 to 97 percent. The errors inherent in the determination of spray volume, evapotranspiration, and deep soil percolation could easily account for the apparent losses of 3 to 9 percent of the applied liquid.

Distribution of water accounted for. The distribution of the liquid accounted for is summarized in Table 9. Monthly distributions between the evaporative losses, runoff, and deep soil percolation for each of the watersheds showed similar patterns due to the influence of climatic conditions and changes in the operating schedule. The evaporative losses showed the characteristic summer peak and the runoff losses showed a concurrent summer low. These results were modified somewhat by the operating schedule changes on June 1, 1968, and October 1, 1968. On June 1 the wastewater spray period was increased from 6 hours per day to 8 hours per day. This 33 percent increase in wastewater loading

TABLE 8

SEASONAL WATER BALANCES

Season		Recovery as Percent of Water Applied				Seasonal Mean
		G-4	G-11	B-11	Y-1	
Spring	mean	103	97	96	103	100
	range	85-127	72-111	74-126	92-125	
Summer	mean	90	91	94	93	92
	range	79-106	77-113	85-109	96-102	
Fall	mean	91	89	92	98	92
	range	83-99	75-104	78-104	90-113	
Winter	mean	88	89	89	90	89
	range	79-112	72-116	70-108	74-106	
Year	mean	92	91	92	97	
	range	79-127	72-116	70-126	74-125	

repressed the increase in evaporative losses as a percentage of the total liquid accounted for and maintained runoff as a substantial fraction of the total throughout the summer months. In October the wastewater spray period was returned to 6 hours per day. This decrease in the daily wastewater load caused a relative increase in the percent evaporative loss. The result was similar evaporative losses for September and October followed by a resumption of the normal seasonal decline in evaporative losses during November. The combined influence of climatic conditions and the changes in the operating schedule caused deep soil percolation to vary in a more random pattern than evaporative losses or runoff. In general, soil percolation losses were relatively greater when evaporative losses were lower.

TABLE 9

PERCENT DISTRIBUTION OF WATER ACCOUNTED FOR ON THE FOUR EXPERIMENTAL WATERSHEDS

	1968								1969				12-month mean
	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	
Watershed G-4													
Evaporative losses	20	24	35	30	18	18	12	9	10	12	19	27	20
Runoff	62	58	40	44	63	58	56	61	68	61	44	42	54
Soil percolation	18	18	25	26	19	24	32	30	22	27	37	31	26
Watershed G-11													
Evaporative losses	21	23	37	--	16	18	--	8	10	3	9	24	17
Runoff	56	57	33	--	65	54	--	65	70	78	61	44	58
Soil percolation	23	20	30	--	19	28	--	27	20	19	30	32	25
Watershed Y-1													
Evaporative losses	22	20	28	21	15	14	9	9	11	4	5	24	15
Runoff	64	68	59	65	74	71	73	69	73	80	81	55	69
Soil percolation	14	12	13	14	11	15	18	22	16	16	14	21	16
Watershed B-11													
Evaporative losses	26	23	36	26	19	19	10	9	10	10	12	28	19
Runoff	53	61	43	61	66	61	68	70	72	70	64	48	61
Soil percolation	21	16	21	13	15	20	22	21	18	20	24	24	20

The difference between the sandy loam soil and the heavier loam and clay loam soils was readily distinguishable by comparing the 12-month data for the four watersheds. The percent runoff was lowest on watersheds G-4 and G-11 which have the sandy loam soil. Runoff from B-11 with the loam soil was intermediate, and the runoff was greatest from Y-1 with the clay loam surface soil.

The percent runoff was also directly related to rainfall events of varying intensity and quantity. The effect of rainfall quantity on percent runoff is shown in Figure 2. The large variability in the data was due to the effects of soil textural class, rainfall intensity, seasonal effects, and errors in measurements. The average runoff for the four watersheds ranged from about 50 percent when there was no rainfall to about 80 percent when rainfall accounted for about 0.6 of the total applied liquid.

Summary and Conclusions

The objective of achieving a water balance of ±10 percent was attained as 93 percent of the calculated volume of applied liquid was accounted for with the water loss measurements used in this study. Evaporative losses accounted for 18 percent of the total liquid applied, runoff accounted for 61 percent, and deep soil percolation accounted for 21 percent. Runoff from the clay loam soil was measurably greater than runoff from the sandy loam soil. Increasing the wastewater load in the summer months maintained the runoff at more than 40 percent. Runoff increased to a maximum of about 80 percent during periods of heavy rainfall.

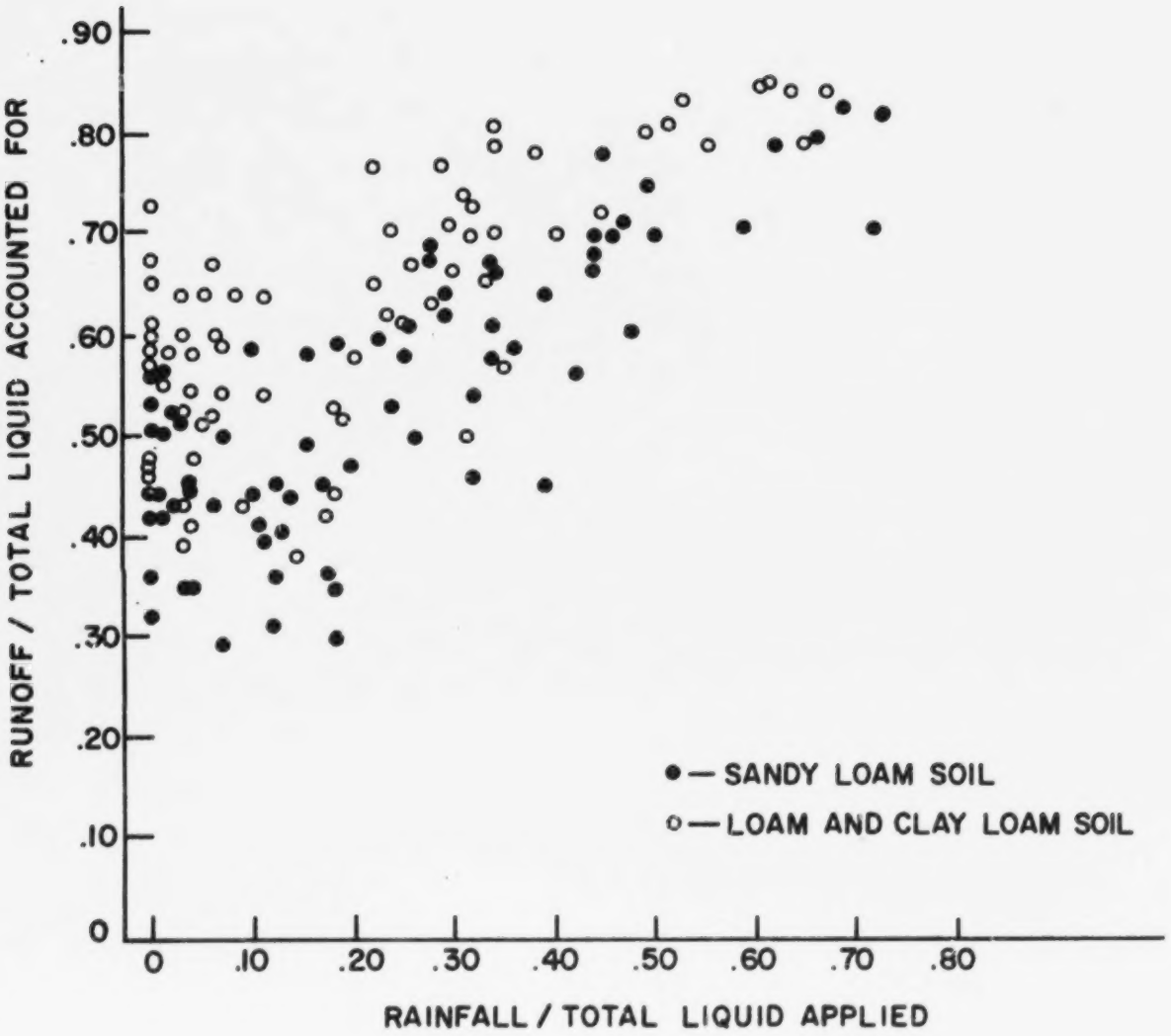

FIGURE 2 – EFFECT OF RAINFALL ON THE FRACTION OF LIQUID RECOVERED AS RUNOFF

CHAPTER V

WATERSHED TREATMENT EFFICIENCIES

Liquid sampling stations to evaluate the treatment efficiencies of the four experimental watersheds were located at the wastewater spray lines and the runoff flumes. Weekly quality data collected at these stations were combined with the hydrological data to obtain the treatment efficiencies on a mass basis.

Methods and Procedures

The runoff was sampled with a flow proportional device to obtain a representative composite sample after each spray period. The sampling device was a modification of one developed by the Tennessee Valley Authority.[2] This sampler consisted of a series of orifices and weirs that took a sample equal to 1/10,000 of the volume passing through the flume. The quality of the liquid samples was determined with the same procedures which were used to characterize the wastewater. Sample analytical forms for the runoff samples are included in Appendix II.

All four watersheds were operated identically from April through October 1968. This period of operation was used to evaluate the effects of system age and soil textural class on treatment efficiency. Watersheds Y-1 and B-11 were operated on different schedules while G-4 and G-11 were kept on the original schedule from November 1968 through April 1969. A second parallel spray line was installed on Y-1 and B-11. This additional line increased the spray-covered area from 40 percent to 75 percent of the watershed area. Smaller nozzles were installed on both of the B-11 lines so that the same weekly load could be maintained without changing the daily spray schedule. Spray nozzles were kept at the same size on Y-1 and the same weekly load was maintained

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[2]Personal communication with James W. Beverage, Chief, Hydraulic Data Branch, Tennessee Valley Authority, Knoxville, Tennessee, February 1968.

by changing to a three-times-a-week spray schedule. The net effect of the changes on B-11 was to maintain the same operating schedule and total load while spreading the load over approximately twice as much soil area. The net effect of the changes on Y-1 was to maintain the same weekly load and unit area load while changing the frequency of application.

Results and Discussion

The characteristics of the wastewater were summarized in Table 6 (Chap. 3). The mean concentrations for the 24-hour composite in Table 6 were the values used to determine all percent concentration changes between the quality of the wastewater and the quality of the watershed runoff.

Runoff quality. The chemical quality of the runoff and the concentration treatment efficiencies for each of the watersheds are summarized in Tables 10, 11, 12, and 13. All watersheds produced a highly treated runoff from April 1968 through October 1968 when the watersheds were all being operated on the same schedule. The data showed that this spray-runoff system was very efficient for the removal of oxygen-demanding substances and suspended solids. It is of particular interest to note that the electrical conductivity and the chloride concentration of the runoff showed a consistent increase of 10 to 15 percent. This was probably the result of evaporation losses which increased the concentration of dissolved salts.

Comparisons of the data for individual watersheds from April 1968 through October 1968 showed that soil textural class and years of service had little, if any, effect on the quality of the runoff or the treatment efficiency as measured by concentration changes. The effect of soil textural class was obtained by comparing the data for G-4, Table 10, to the data for Y-1, Table 13, and the data for G-11, Table 11, to the data for B-11, Table 12. These direct comparisons showed that soil textural

TABLE 10

MEAN CHEMICAL QUALITY OF RUNOFF AND CONCENTRATION TREATMENT EFFICIENCY FOR WATERSHED G-4

Chemical Parameter	Apr. '68 thru Oct. '68		Nov. '68 thru Apr. '69	
	Runoff Quality[a]	Concentration Change %	Runoff Quality[a]	Concentration Change %
pH	7.0	---	7.7	---
EC	520	+16	460	+ 2
Cl	50	+11	44	0
M.O. Alk.	132	+95	142	+110
TSS	10	-96	19	- 92
VSS	6	-97	12	- 94
TP	4.1	-45	4.2	- 43
NO_3-N	0.10	-50	<0.05	---
NO_2-N	<0.05	---	<0.05	---
NH_3-N	0.2	-80	---	---
Kjeldl. N	2.9	-83	3.3	- 81
Total-N	3.0	-83	3.4	- 80
COD	65	-92	70	- 91
TOC	27	-89	22	- 91
BOD	9	-98	11	- 98

[a]All concentrations in mg/l except: pH - units; EC - μmhos/cm

Note: Abbreviations of chemical parameters are explained in Appendix I.

TABLE 11

MEAN CHEMICAL QUALITY OF RUNOFF AND CONCENTRATION TREATMENT EFFICIENCY FOR WATERSHED G-11

Chemical Parameter	Apr. '68 thru Oct. '68		Nov. '68 thru Apr. '69	
	Runoff Quality[a]	Concentration Change %	Runoff Quality[a]	Concentration Change %
pH	7.0	---	7.4	---
EC	520	+ 16	490	+ 9
Cl	50	+ 11	45	+ 2
M.O. Alk.	131	+ 94	139	+106
TSS	20	- 92	31	- 87
VSS	13	- 94	24	- 89
TP	5.0	- 32	4.4	- 41
NO_3-N	0.5	+150	<0.05	---
NO_2-N	<0.05	---	<0.05	---
NH_3-N	0.2	- 80	---	---
Kjeldl. N	3.6	- 79	4.2	- 75
Total-N	4.1	- 76	4.2	- 75
COD	92	- 89	160	- 80
TOC	31	- 88	51	- 80
BOD	11	- 98	62	- 89

[a]All concentrations in mg/l except: pH - units; EC - μmhos/cm

Note: Abbreviations of chemical parameters are explained in Appendix I.

TABLE 12

MEAN CHEMICAL QUALITY OF RUNOFF AND CONCENTRATION TREATMENT EFFICIENCY FOR WATERSHED B-11

Chemical Parameter	Apr. '68 thru Oct. '68		Nov. '68 thru Apr. '69	
	Runoff Quality[a]	Concentration Change %	Runoff Quality[a]	Concentration Change %
pH	7.0	---	7.5	---
EC	500	+11	470	+ 5
Cl	49	+11	42	- 5
M.O. Alk.	107	+58	138	+104
TSS	23	-91	33	- 87
VSS	18	-92	25	- 89
TP	5.9	-30	4.7	- 37
NO_3-N	0.10	-50	<0.05	---
NO_2-N	<0.05	---	<0.05	---
NH_3-N	0.1	-90	---	---
Kjeldl. N	5.9	-65	4.8	- 72
Total-N	6.0	-65	4.8	- 72
COD	119	-85	120	- 85
TOC	49	-80	37	- 85
BOD	13	-98	34	- 94

[a]All concentrations in mg/l except: pH - units; EC - µmhos/cm

Note: Abbreviations of chemical parameters are explained in Appendix I.

TABLE 13

MEAN CHEMICAL QUALITY OF RUNOFF AND CONCENTRATION TREATMENT EFFICIENCY FOR WATERSHED Y-1

Chemical Parameter	Apr. '68 thru Oct. '68		Nov. '68 thru Apr. '69	
	Runoff Quality[a]	Concentration Change %	Runoff Quality[a]	Concentration Change %
pH	7.2	---	7.6	---
EC	500	+ 11	470	+ 5
Cl	49	+ 11	43	- 2
M.O. Alk.	135	+100	124	+84
TSS	22	- 91	24	-90
VSS	12	- 94	16	-93
TP	4.5	- 39	2.3	-69
NO_3-N	0.06	- 70	0.12	-40
NO_2-N	<0.05	---	<0.05	---
NH_3-N	0.3	- 70	---	---
Kjeldl. N	3.6	- 79	2.9	-83
Total-N	3.7	- 79	3.0	-83
COD	76	- 91	91	-89
TOC	29	- 88	28	-88
BOD	8	- 99	24	-96

[a]All concentrations in mg/l except: pH - units; EC - μmhos/cm

Note: Abbreviations of chemical parameters are explained in Appendix I.

class had no appreciable effect on the quality of the runoff or the treatment efficiency as measured by concentration changes. The effect of system age was obtained by comparing the data for G-4 to that of G-11 and the data for Y-1 to that of B-11. In this comparison the older watersheds G-4 and Y-1 showed a minor but definite advantage over their younger counterparts G-11 and B-11.

During the period from November 1968 through April 1969, watersheds G-4 and G-11 were continued on the same operating schedule while watersheds Y-1 and B-11 were used to evaluate the effects of different operating schedules on the quality of the runoff and the treatment efficiency. A comparison of data for watershed G-4, Table 10, showed that the quality of the runoff and the treatment efficiency remained essentially unchanged. The data showed this soil system was capable of achieving excellent treatment throughout the calendar year. The other control watershed, G-11, failed to maintain the same runoff quality as it had during the warmer months, although the treatment efficiency was equal to or better than that of conventional treatment plants (17). The spray line for this watershed was plagued with mechanical malfunctions throughout this six-month period. These malfunctions caused the watershed to receive excessive quantities of wastewater through leaks and unscheduled wastewater sprays. The results for the other three watersheds substantiate the authors' opinion that the relatively lower treatment efficiency for this watershed was caused by the overloading due to the mechanical malfunctions of the spray line.

Watershed Y-1 was operated on a three-times-per-week spray schedule instead of the regular once-per-day schedule. This change in schedule produced a substantial improvement in the phosphorus removal while maintaining the excellent treatment efficiency achieved during the first six months for most of the other parameters. A notable exception was the loss in BOD removal as indicated by the increase in the BOD concentration from 8 mg/1 for April 1968 through October 1968 to 24 mg/1 for

November 1968 through April 1969. This increase may be partially due to seasonal effects, but the results for the control watershed G-4 indicate that most of the BOD change was due to the change in the operational schedule. The instantaneous loading rate for Y-1 was increased from 0.13 inches per hour to 0.17 inches per hour concurrent with the change to the three-times-per-week spray schedule. It is possible that this change contributed to the loss of BOD removal since it reduced the liquid detention time on the watershed slope.

Watershed B-11 was operated on the same once-per-day spray schedule, but the wastewater was spread over about 75 percent of the watershed area instead of the original 40 percent of the area. The data for the two 6-month periods, Table 12, do not show a consistent change in treatment efficiency. Phosphorus, total nitrogen, and total organic carbon removals were increased while BOD removal was decreased after the operational change. Spreading the wastewater load over more of the available area did not improve runoff quality for this watershed.

Mass removal efficiencies. The concentration reductions do not give a complete picture of the treatment efficiency because there is a substantial volume reduction as well as concentration changes. Five key parameters were selected for this evaluation and monthly data are presented in Tables 14 and 15.

The data for April 1968 through October 1968 which are presented in Table 14 showed results which differ considerably from the concentration reductions. Mass removal percentages were greater for all five parameters. Phosphorus showed the greatest improvement with an increase of about 20 percent. Although the concentration data showed no effect due to soil textural class, the mass removal data showed that the sandy loam soil on watersheds G-4 and G-11 gave small but consistently better removals than the loam and clay loam soils on B-11 and Y-1. This difference was the result of smaller runoff percentages for the sandy loam

TABLE 14

MEAN MASS REMOVAL PERCENTACES FROM APRIL 1968 THROUGH OCTOBER 1968

Experimental Line	Apr.	May	June	July	Aug.	Sept.	Oct.	Weighted Average
				BOD				
G-4	98.5	99.2	98.4	99.5	99.2	99.0	99.3	99.1
Y-1	98.0	98.6	98.7	99.4	97.7	99.5	98.6	98.7
G-11	98.5	99.3	98.8	99.4	----	99.1	99.2	99.1
B-11	85.1	----	97.2	98.2	----	----	99.1	96.5
				COD				
G-4	95.7	93.8	94.0	96.8	92.4	95.9	97.5	95.7
Y-1	94.8	90.7	91.5	95.5	84.7	93.5	94.9	93.3
G-11	93.9	89.0	93.2	96.6	----	96.4	97.0	94.3
B-11	79.6	----	89.0	94.0	95.3	97.6	95.1	91.3
				VSS				
G-4	99.7	99.2	97.0	98.5	97.7	99.4	97.8	98.3
Y-1	94.9	92.6	94.3	98.1	96.0	98.3	95.0	95.5
G-11	96.1	95.1	95.6	97.1	----	99.2	94.4	96.0
B-11	80.3	----	----	96.2	97.2	96.9	96.1	93.4
				T-N				
G-4	90.6	89.1	90.3	91.9	73.2	82.8	95.3	90.7
Y-1	85.6	80.0	82.0	90.6	61.2	90.9	93.6	86.2
G-11	90.0	82.1	88.5	92.5	----	89.5	96.0	90.1
B-11	76.5	----	70.3	90.2	82.4	91.5	92.3	86.6
				T-P				
G-4	85.6	57.1	67.9	62.8	83.2	52.0	53.8	64.6
Y-1	86.7	52.8	53.9	50.7	82.4	-31.8	16.3	48.6
G-11	86.6	65.6	44.7	54.4	----	55.8	60.9	61.5
B-11	74.4	----	40.2	29.9	88.3	-0.1	58.9	50.4

Note: Abbreviations of chemical parameters are explained in Appendix I.

TABLE 15

MEAN MASS REMOVAL PERCENTAGES FROM NOVEMBER 1968 THROUGH APRIL 1969

Experimental Line	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Weighted Average
			BOD				
G-4	99.4	99.4	99.1	99.3	99.5	98.5	99.1
Y-1	99.9	97.7	97.3	98.0	99.4	98.3	98.0
G-11	----	94.2	92.6	----	95.8	94.5	94.0
B-11	99.2	93.9	97.8	97.5	98.5	94.0	96.8
			COD				
G-4	97.3	97.2	96.5	98.1	97.9	95.0	96.6
Y-1	95.6	95.4	96.3	97.6	98.3	95.5	96.2
G-11	----	84.8	92.2	----	93.8	90.7	90.9
B-11	94.2	91.3	94.3	96.7	96.5	81.6	92.8
			VSS				
G-4	98.5	99.2	98.8	99.6	98.9	96.3	98.2
Y-1	98.4	98.6	98.2	98.6	98.4	95.8	97.6
G-11	----	93.5	97.3	----	96.4	91.8	94.9
B-11	97.9	88.0	98.4	98.4	98.3	83.6	94.6
			T-N				
G-4	94.9	96.1	92.4	94.3	96.7	86.3	92.2
Y-1	95.5	95.3	93.8	91.9	97.5	92.9	93.9
G-11	----	90.3	92.6	----	93.8	83.1	89.3
B-11	92.4	93.2	92.5	94.4	95.0	63.2	88.9
			T-P				
G-4	75.9	69.4	38.2	72.1	55.4	59.6	58.5
Y-1	66.9	75.6	76.8	87.7	88.9	88.6	81.2
G-11	----	37.0	55.6	----	71.5	69.3	61.4
B-11	56.9	43.6	44.8	67.1	62.1	59.0	55.5

Note: Abbreviations of chemical parameters are explained in Appendix I.

soil. The slight advantage which was shown for the older watersheds by the concentration data was less evident for the mass removal data. These minor effects due to soil textural class and system age indicate that any soil textural class is suitable for use in a soil treatment system and that this system has had no loss in treatment efficiency after more than four years of use.

The data for November 1968 through April 1969 are presented in Table 15. The data for watershed G-4 corroborated the results of the concentration data and showed that consistently high removals were maintained throughout the calendar year. The data for G-11 showed the loss in treatment efficiency which was attributed to mechanical malfunctions in the discussion of the concentration data. The mass removal for B-11 showed a slight but consistent improvement over the results for the first six months of the study. This result was different from the result observed for concentration reductions and suggested that overall system efficiency might be improved by spreading the wastewater load over 75 percent instead of 40 percent of the soil area. The change in the removal of total phosphorus on watershed Y-1 is shown clearly by the monthly data in Table 15. An apparent transition period from November 1968 through January 1969 was followed by consistent mass removals of about 88 percent for the last three months of the study. This is an increase of 40 percent over the average removal of 48 percent achieved during the first six months and shown in Table 14. This watershed also showed slight improvements in the removal of total nitrogen, VSS, and COD, but there was a slight decline in BOD removal. These results showed that the overall treatment efficiency of this soil treatment system could be improved by changing the present once-per-day application schedule to a three-times-per-week schedule.

Summary and Conclusions

The results of this 12-month study showed that the individual watersheds in this soil system achieved a very high degree of treatment. Mass removal efficiencies were substantially better than concentration reduction efficiencies because the runoff ranged from 40 to 80 percent of the applied wastewater. Soil textural class and system age had very little effect on treatment efficiencies. Treatment was excellent throughout the calendar year but there may have been a slight decline in the winter months.

Although the present system design and operating schedule do provide excellent treatment, the results of this study showed that mass removal was improved by spreading the wastewater load over a greater fraction of the land area and by reducing the frequency of application. The greatest change was in phosphorus removal which was increased from 48 percent to 88 percent on watershed Y-1 by changing from a once-per-day to a three-times-per-week application schedule.

CHAPTER VI

FARM EFFLUENT QUALITY

Farm effluent quality was monitored at three locations for varying periods during the 12-month study. Two 55-acre watersheds representative of the older part of the treatment system and one 20-acre watershed on the younger part of the system were sampled. All three watersheds were completely contained within the treatment system and received no runoff from outside sources.

Methods and Procedures

The electrical conductivity of the wastewater and farm effluent was monitored continuously. Grab samples of the farm effluent for chemical analyses were obtained weekly. These grab samples were compared to 24-hour composite samples on several occasions to verify that the grab samples were representative samples. The composite samples of the stream were obtained with a constant-speed pump sampler. The farm effluent samples were analyzed in the same manner as the wastewater and watershed runoff.

Results and Discussion

Continuous conductivity monitoring. Mean daily values of the electrical conductivity of the wastewater and farm effluent are shown in Figure 3. The much greater fluctuation in the electrical conductivity of the farm effluent resulted from the influence of rainfall events. There was a general increase in the electrical conductivity of the farm effluent from May 1968 through July 1968 followed by a sharp decrease in early September 1968. This increase closely paralleled the increase in evaporative losses described in the hydrology chapter and the increase was probably the result of concentrating effects due to evaporation losses.

The effect of rainfall on the electrical conductivity of the farm effluent is shown in Figure 4. The data summarized in this figure showed that rainfall events of 0.1 inch or less had

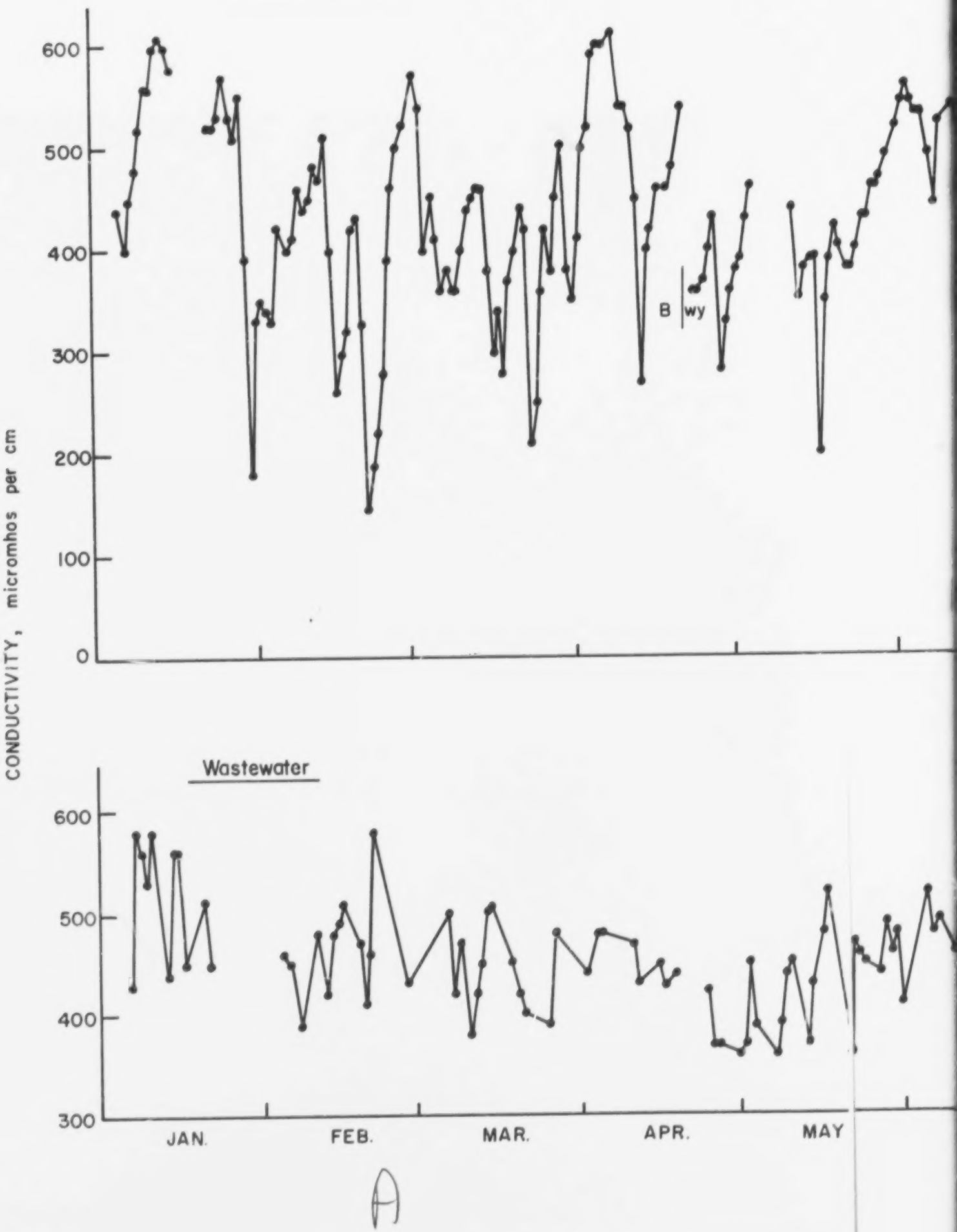
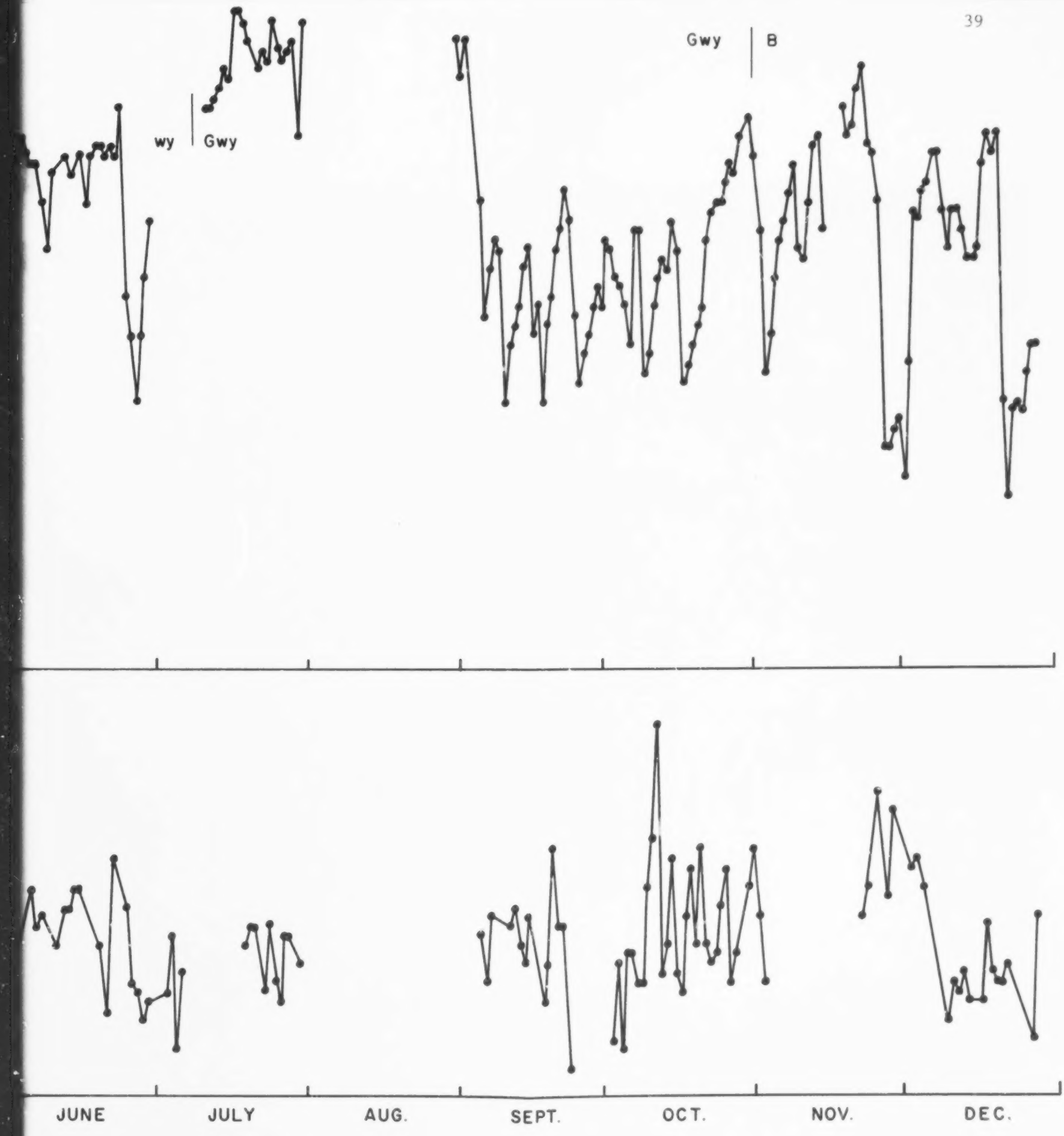


FIGURE 3 – DAILY MEAN ELECTRICAL CONDUCTIVITIES



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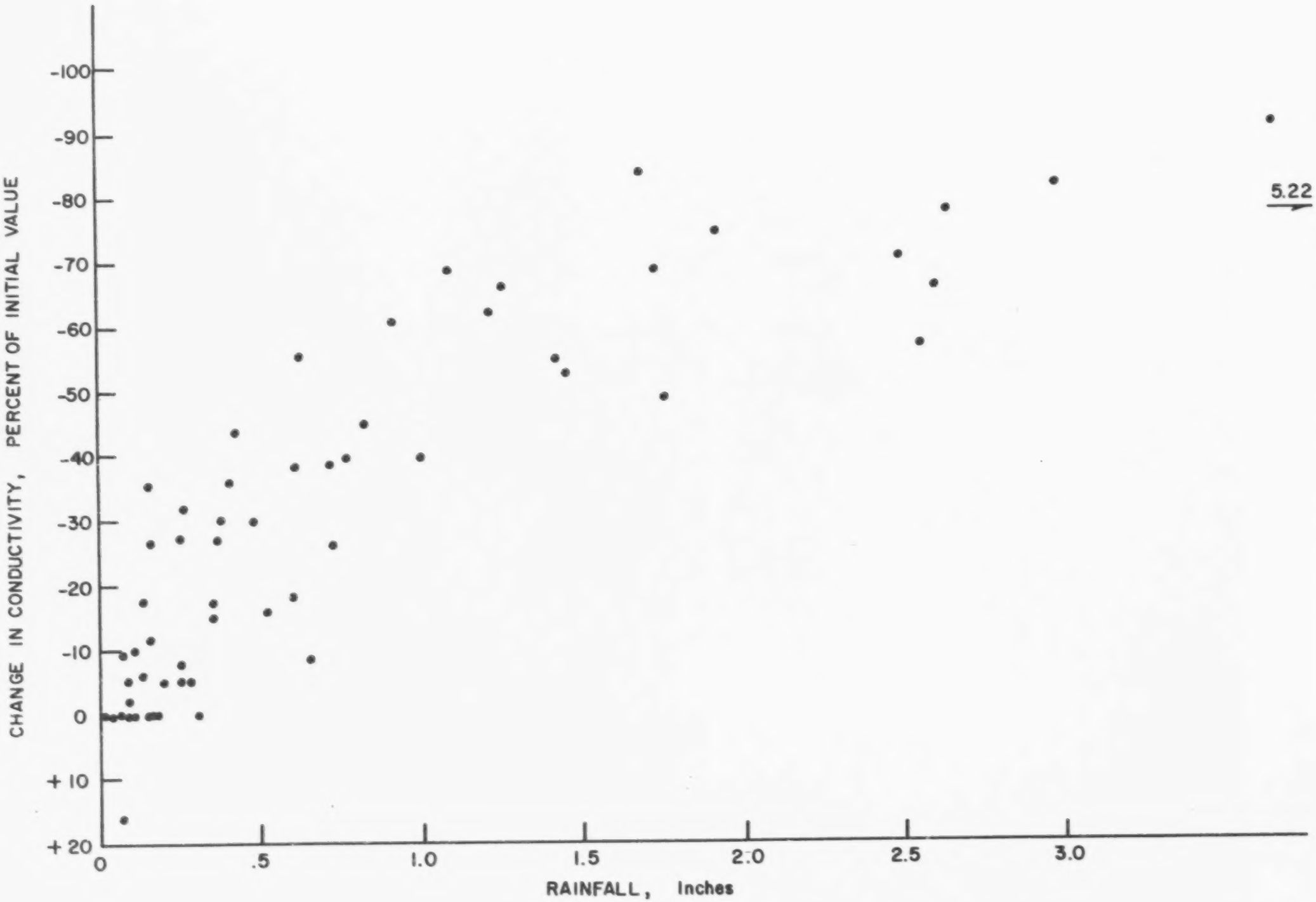

FIGURE 4 - EFFECT OF RAINFALL ON ELECTRICAL CONDUCTIVITY OF FARM EFFLUENT

little, if any, effect on the conductivity of the runoff water. Such rainfall events did not contribute enough volume to alter the composition of the runoff contributed by the applied wastewater. Rainfall events of 0.1 inch to about 2.0 inches had a marked effect on the conductivity of the runoff. The volumes contributed by rainfalls in this range diluted the runoff to a steadily increasing degree. Rainfall events greater than 2.0 inches had little additional effect on the conductivity.

Another interesting relationship was the diurnal variation in the conductivity. This relationship is shown in Figures 5 and 6. The plant operational schedule included a daily cleanup starting at about midnight. The effect of this cleanup on the conductivity of the wastewater is clearly demonstrated in Figure 5. The data plotted in this figure also emphasized that there was no relationship between seasons and the conductivity of the wastewater during the processing period of the day. The diurnal changes in the farm effluent conductivity are shown in Figure 6. There was no peak associated with the daily cleanup period. The spray-runoff system acted as a buffer and virtually eliminated the effect of the cleanup period on the field effluent conductivity. Arranging the data by seasons clearly demonstrated the seasonal changes in the farm effluent conductivity which have already been discussed.

Chemical quality of farm effluent. The chemical quality of the farm effluent from the three monitoring locations is summarized in Table 16. The quality of the effluent varied considerably from one location to another, but each sampling site produced an effluent of very high quality. The pH, electrical conductivity, and chloride differences are similar to seasonal differences which were observed for individual watersheds. These differences did not represent a difference in treatment capacity.

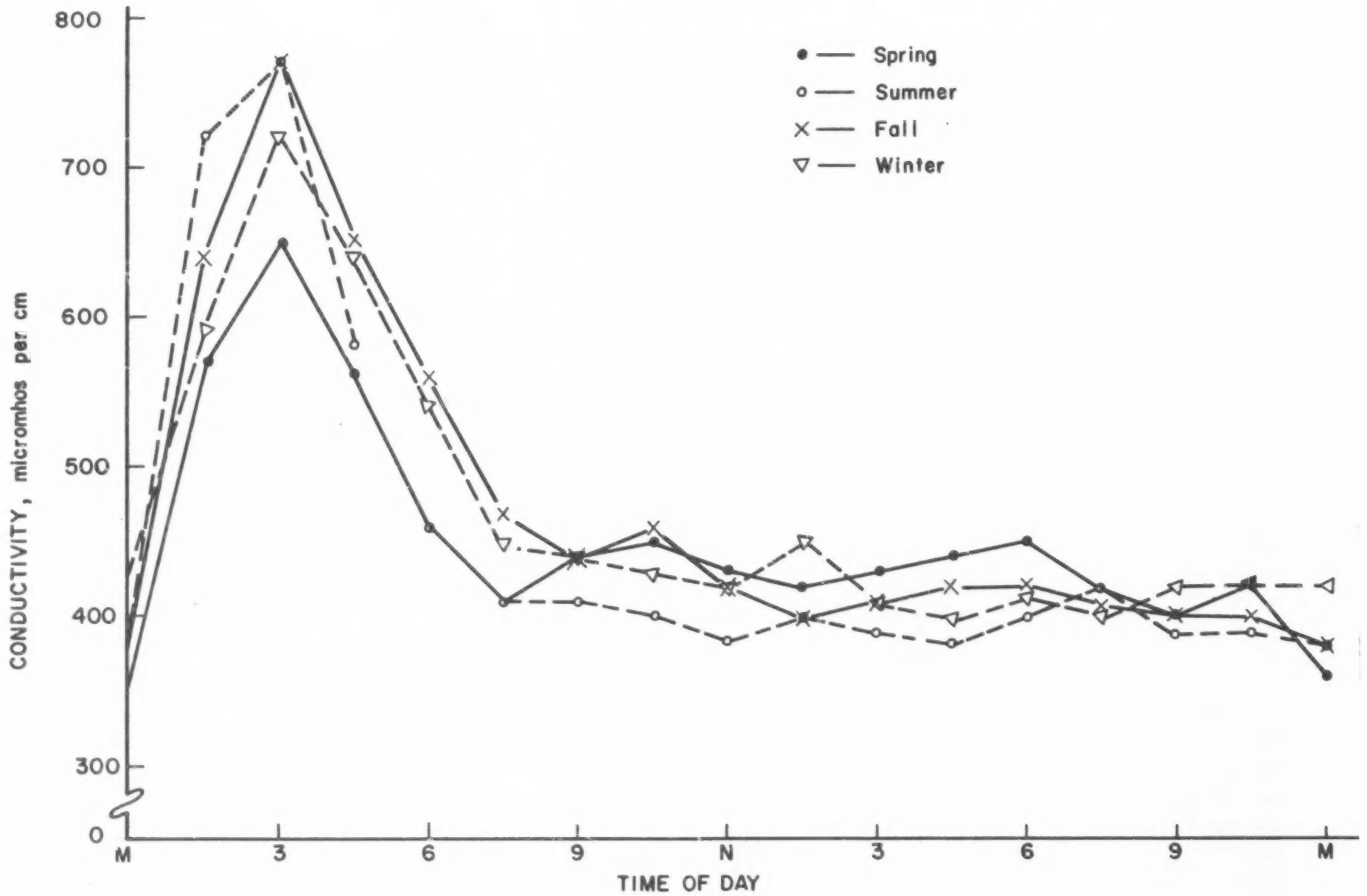

FIGURE 5 - DIURNAL VARIATION OF ELECTRICAL CONDUCTIVITY OF WASTE WATER

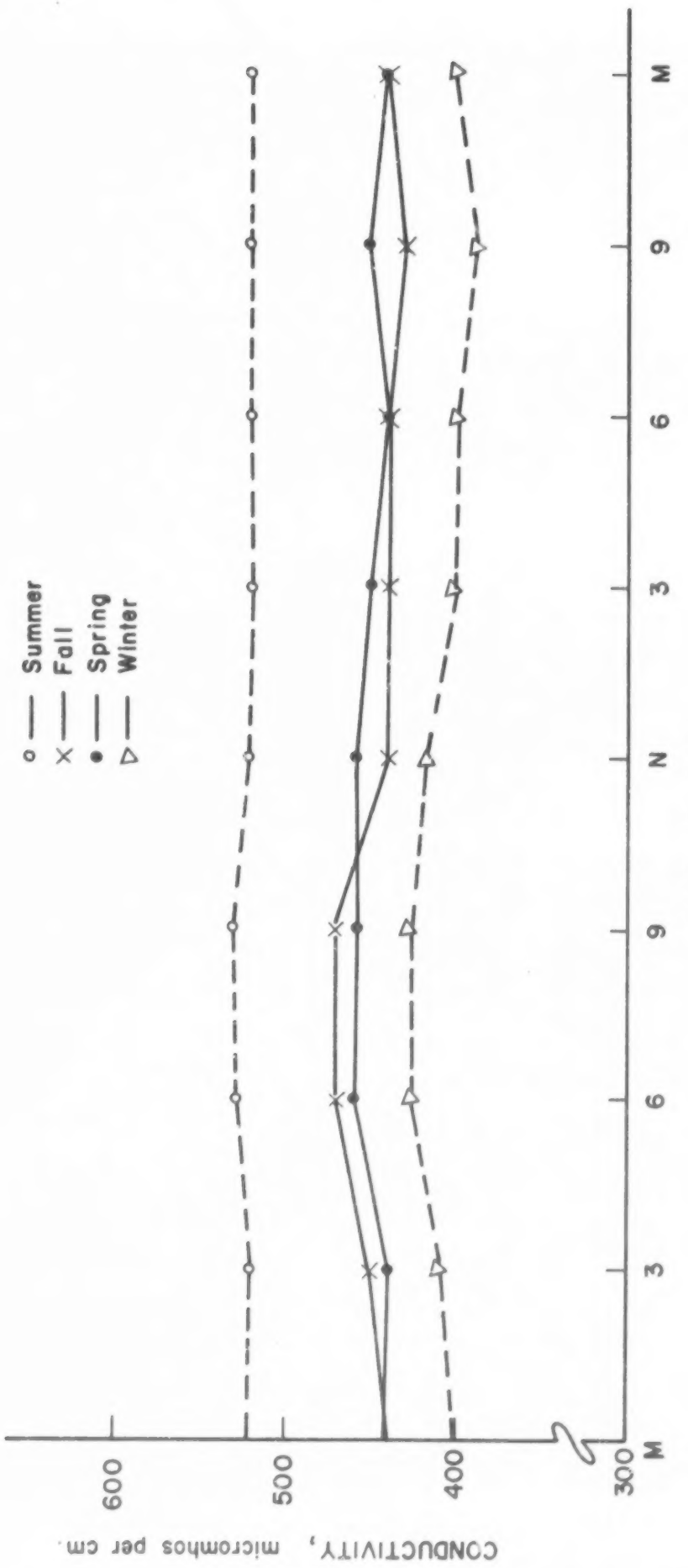

FIGURE 6 - DIURNAL VARIATION OF ELECTRICAL CONDUCTIVITY OF FARM EFFLUENT

TABLE 16

FARM EFFLUENT QUALITY AND CONCENTRATION
TREATMENT EFFICIENCY, MEAN VALUES[a]

Chemical Parameter	Three watersheds separately			All data combined	
	WY (old)	GWY (old)	B (new)	Concentration	Concentration change, percent
pH, units[b]	6.8	7.2	7.6	7.2	---
EC, µmhos/cm	430	520	500	490	+ 9.6
Cl	40	48	50	47	+ 6.6
M.O. Alk	124	128	136	130	+92.6
TSS	23	14	13	16	-93.5
VSS	11	6	8	8	-96.3
T-P	3.9	4.1	4.9	4.3	-42.5
NO_3-N	0.2	0.3	<0.5	0.2	---
NO_2-N	<0.05	<0.05	<0.05	<0.05	---
NH_3-N	0.2	---	---	0.5	---
Kjeldl. N	2.6	2.5	2.8	2.6	-84.7
Total-N	2.8	2.8	2.8	2.8	-83.9
COD	63	50	75	67	-91.7
TOC	25	24	21	23	-90.8
BOD	6	7	16	9	-98.4

[a] All concentrations in mg/l except where noted
[b] Median values instead of a mean

Note: Abbreviations of chemical parameters are explained in Appendix I.

The higher concentration of oxygen-demanding substances in the B-area effluent substantiated the results observed for individual watersheds where it was shown that the younger areas were somewhat less efficient than the older areas.

The mean concentrations, based on all data combined, showed that the farm effluent is similar in quality to the runoff from the individual watersheds when they are performing satisfactorily as all four of the experimental watersheds were from April 1968 through October 1968 (Tables 10, 11, 12, and 13). One consistent difference of significance was the total nitrogen concentration. The total nitrogen content of the runoff from the four experimental watersheds ranged from 3.0 to 6.0 mg/l from April through October 1968, while the concentration in the farm effluent was 2.8 mg/l. This difference indicated that additional reduction in the concentration of total nitrogen was achieved as the liquid flowed through the collection channels to the locations where the farm effluent samples were collected.

Summary and Conclusions

The results of analyses conducted on samples collected from three different sites during the 12-month study showed that the farm effluent was similar in composition to the runoff from the four experimental watersheds when the experimental watersheds were achieving their best treatment efficiency. The spray-runoff treatment system acted as a buffer to prevent wide diurnal variations in the wastewater quality to show up in the quality of the farm effluent. Seasonal variations in the electrical conductivity of the farm effluent could be related to evaporative losses of water with the resultant increase in dissolved solids concentration. The electrical conductivity of the farm effluent was decreased proportionately by rainfall events from 0.1 inch to 2.0 inches. Rainfall events above this range had little additional effect on the electrical conductivity.

CHAPTER VII

SOIL AND SOIL WATER

Soil samples were obtained from each experimental watershed and from the border areas in the watershed vicinity. The border area samples were used as controls to evaluate the effects of wastewater spraying on soil properties. Soil water samples were obtained at the 3-foot depth to determine the quality of the liquid percolating through the soil.

Methods and Procedures

Soil samples were taken at the 0- to 2-inch and 11- to 13-inch depths. Each sample was obtained by compositing 15 subsamples selected systematically to represent the average soil composition. Routine procedures for crushing, mixing, and subdividing the samples were used to prepare the soil samples for analysis or extraction. The analytical procedures and extraction procedures were selected from those presently recommended for routine soil analyses (18).

The soil water samples were obtained with soil water samplers which consist of a porous ceramic tip bonded to plastic pipe. When necessary, vacuum was applied to the sampler to withdraw liquid from unsaturated soil. Six of these samplers were installed on each watershed to obtain a composite sample representative of the whole watershed. Samples were taken once a month and subjected to chemical analysis to determine the soil water quality. Analytical procedures for the soil water samples were obtained from the same source as the procedures for surface water samples. A sample of the chemical data form for soil water samples is included in Appendix III.

Results and Discussion

Soil analyses. The results of the analyses on the soil samples are summarized in Table 17. With the exception of experimental line B-11 soil, pH was similar for the sprayed and non-sprayed samples at both sampling depths. Conductivity at

TABLE 17

SOIL SAMPLE ANALYSES

Experimental Area	pH	Conductivity millimhos/cm	Cation Exchange Capacity (CEC) and Exchangeable Cations, me/100 g					Exchangeable Na Percentage	gm/100 gm	
			CEC	Ca	Mg	K	Na		Total-P	Organic Carbon
0- to 2-inch plot samples										
G-4	6.5	0.16	16.2	6.4	0.7	0.5	0.5	5.8	0.042	0.94
Y-1	6.2	0.14	30.3	11.6	1.5	0.8	0.7	4.6	0.043	1.42
G-11	6.5	0.16	15.2	6.4	0.7	0.3	0.9	10.3	0.046	0.71
B-11	6.2	0.10	13.1	5.8	0.7	0.4	0.4	5.9	0.023	1.46
0- to 2-inch border samples										
G-4	6.2	0.08	23.8	9.8	2.0	0.5	0.3	2.6	0.027	1.92
Y-1	6.7	0.10	32.1	14.6	1.8	0.6	0.2	1.0	0.036	1.91
G-11	6.4	0.06	21.2	9.6	1.0	0.6	0.6	5.0	0.026	0.94
B-11	5.1	0.05	22.8	6.1	1.6	0.3	0.2	2.7	0.015	0.75
11- to 13-inch plot samples										
G-4	5.0	0.12	27.6	7.2	2.9	0.2	1.0	9.1	0.018	0.41
Y-1	4.8	0.12	40.0	9.7	2.4	0.2	0.9	7.0	0.010	0.56
G-11	5.0	0.11	38.4	13.8	2.5	0.3	0.5	3.1	0.090	0.34
B-11	4.7	0.10	43.6	9.4	2.1	0.2	0.9	7.6	0.013	0.45
11- to 13-inch border samples										
G-4	5.3	0.11	25.8	9.3	3.1	0.2	1.2	8.6	0.017	0.68
Y-1	5.2	0.09	45.2	15.0	3.0	0.3	0.6	3.0	0.015	0.60
G-11	5.2	0.05	24.5	3.8	0.5	0.1	0.3	5.8	0.017	0.34
B-11	4.7	0.07	36.0	10.2	2.5	0.2	0.7	5.3	0.017	0.38

Note: Abbreviations of chemical parameters are explained in Appendix I.

the 0- to 2-inch depth under spray was approximately double that of the non-sprayed area. This effect was much less noticeable at the 11- to 13-inch depth. The conductivity of all samples was representative of a strongly leached soil. The data for exchangeable cations showed a definite change at the 0- to 2-inch depth, but the effect was not noticeable at the 11- to 13-inch depth. At the 0- to 2-inch depth, there was a decrease in exchange capacity and the exchangeable cations, calcium and magnesium. There was an increase in exchangeable sodium and the exchangeable sodium percentage. Although these changes indicated a trend toward detrimental sodium effects on the soil, they did not indicate conditions to be concerned about at this time. The fact that the younger spray lines, G-11 and B-11, exhibited changes similar to the older lines, G-4 and Y-1, suggested that changes may approach an equilibrium condition after three to five years of operation.

The phosphorus content of the soil in the sprayed area increased at the 0- to 2-inch depth, but there was no consistent effect shown at the 11- to 13-inch depth. These increases in the 0- to 2-inch depth for the sandy loam areas, G-4 and G-11, were equal to about 1300 lbs/acre, and the increases for the heavier soils, Y-1 and B-11, were equal to about 600 lbs/acre. Since phosphorus removal from the wastewater is about 300 lbs/acre/year, the phosphorus accumulating in the soil accounts for a significant fraction of phosphorus removal.

The organic carbon content of the 0- to 2-inch samples was lower under the spray lines for three of the four test areas. It would appear that biological degradation of the plant residue prevented a buildup in the organic matter content of the surface soil. Organic carbon content at the 11- to 13-inch depth was not affected by the wastewater spraying. Maintaining the organic matter content of the surface soil should be considered in the

selection of crop harvesting schedules. Some organic residue must be returned to the soil to prevent biological depletion of the native organic matter to the point where it becomes detrimental to the operation of the treatment system.

Soil water quality. The results of the soil water analyses are summarized in Table 18. The quality of the soil water under the four experimental areas varied substantially. The most obvious and greatest differences were related to system age. All of the parameters except total phosphorus exhibited differences related to system age. The older areas, G-4 and Y-1, had soil water with a higher pH and generally greater concentrations for all of the other parameters. The total dissolved salts were estimated by conductivity to be 2 to 4 times greater for these areas than for the younger areas, G-11 and B-11. The concentrations of nitrogen and phosphorus were of particular interest since the treatment efficiency evaluation showed that they were removed from the runoff by the treatment system. The data for the soil water samples showed that these constituents were not being released to groundwater by deep percolation. Less than one percent of the applied phosphorus and about 2 percent of the applied nitrogen were contained in the soil water percolating past the 3-foot depth. The soil water should be monitored again after a few years to determine if the present conditions under G-4 and Y-1 are approaching a stable state. If salinity continues to increase, it could become a problem and impose limitations on the usefulness of the system at sometime in the future.

Summary and Conclusions

Soil samples and soil water samples were collected to evaluate the effects of the wastewater applications on soil properties. There was a salinity increase with age in the soil and in the soil water. Present salinity levels are not detrimental and a comparison of the 3- and 5-year-old areas of the treatment

TABLE 18

SUMMARY OF SOIL WATER ANALYSES

Experimental Area		pH	Conductivity µmhos/cm	Concentration, mg/liter							
				Total Phosphorus	Total Nitrogen	Na	Ca	Mg	K	Cl	SO_4
G-4	median	6.7	1300	0.3	3.1	240	66	15	0.9	190	413
	range	5.0-7.4	830-2000	<.05-1.4	1.5-5.0	204-264	38-109	8-21	0.3-5.7	164-720	300-570
Y-1	median	6.6	1300	0.4	2.2	198	66	12	0.4	236	212
	range	6.0-6.8	750-2900	<.05-1.6	1.8-4.0	130-314	20-137	4-40	0.2-2.8	180-508	120-290
G-11	median	6.0	240	0.6	0.2	25	16	2.6	0.2	65	10
	range	5.3-7.2	160-350	<.05-1.5	<0.1-2.1	20-30	6-24	1.0-13	0.1-0.6	40-240	6-25
B-11	median	5.9	600	0.1	1.4	109	17	2.4	0.2	138	74
	range	5.5-6.9	440-750	<.05-1.1	0.3-5.5	100-114	14-22	0.5-14	<0.1-1.0	63-160	55-94

system suggests that the level of salinity is approaching an equilibrium level. The salinity increase was primarily due to sodium and the exchangeable sodium percentage also increased considerably. A substantial fraction of the phosphorus removed from the wastewater was retained in the soil at the 0- to 2-inch depth. Only a negligible fraction of the total phosphorus and nitrogen removed from the wastewater was retained in the soil water percolating past the 3-foot depth.

CHAPTER VIII

SUPPLEMENTAL STUDIES

Several short-term studies were conducted during the 12-month experimental period. These studies were conducted to clarify questions arising from routine experimental procedures. In addition, opportunities to obtain information of a special nature were often provided by unscheduled changes in operation of the treatment system. The results of these studies are presented as indications rather than conclusions since they are based on a limited quantity of data.

Slope Study

A one-day study compared the runoff quality at the midpoint on the slope to the runoff quality at the toe of the slope on watershed Y-1. The midpoint of the slope was 80 feet from the spray line (40 feet from the perimeter of the spray pattern), and the toe of the slope was 160 feet from the spray line (120 feet from the perimeter of the spray pattern). Spray samples from a single nozzle were collected as 2-hour composites during a 6-hour spray period. Similar composite samples were taken at the midpoint and toe of the watershed slope.

The effect of the distance downslope on the quality of the applied wastewater is summarized in Table 19. On this one-day study the distance downslope had little effect on pH or electrical conductivity. The reduction in COD and TOC concentrations at 40 feet were equal to the reductions at 120 feet downslope from the spray pattern. Additional reduction in the phosphorus concentration was achieved between 40 feet and 120 feet downslope. There was an indication that a minimum nitrogen concentration occurred at 40 feet downslope, and there was an increase in nitrogen between 40 feet and 120 feet. The results of this study suggested that optimum overall treatment for this soil treatment system would be achieved with a downslope run somewhere between 40 and 120 feet.

TABLE 19

TREATMENT EFFICIENCY VERSUS DISTANCE
DOWNSLOPE FROM SPRAY LINE

Distance downslope from spray perimeter, feet	pH	cond. µmhos/cm	Concentration mg/l				
			TSS	TP	TN	COD	TOC
0	8.8	570	430	5.6	15.0	1060	355
40	8.1	600	8	3.0	0.7	43	18
120	7.9	600	---	2.5	1.0	43	19

Note: Abbreviations of chemical parameters are explained in Appendix I.

Filter Study

The physical removal of contaminants by filtration was evaluated by filtering a wastewater sample through a coarse filter paper (S&S No. 588). Portions of the whole wastewater sample and the filtrate were analyzed to determine the amount of contaminant removed by filtration. The analytical results are summarized in Table 20.

The analytical results for this single sample showed that 60 to 70 percent of the contaminants were not removed by this coarse filter paper. These results suggested that physical and chemical adsorption play an important role in retaining contaminants on the slopes of the watersheds long enough for the microbial population to degrade the organic contaminants.

Nitrate Study

Deviations in nitrate concentration between wastewater grab samples and spray composite samples had been noticed. To determine the cause, grab samples were obtained from the wastewater sump. An initial analysis was performed on each sample and hourly thereafter. As shown in

TABLE 20

CONTAMINANTS REMOVED BY FILTRATION

Sample	Concentration, mg/l			
	Total-P	COD	TOC	BOD
Whole wastewater	4.0	577	312	577
Filtrate	2.8	352	188	391
Percent removal	30	40	40	32

Note: Abbreviations of chemical parameters are explained in Appendix I.

Figure 7, the nitrate decline rate and the nitrite incline rate are similar in appearance. The nitrate had depleted between the third and fourth hour. The nitrite values had increased to the maximum point by the third hour and declined to near depletion by the sixth hour.

This change of values was due to bacterial action in the collection bottle, depleting the dissolved oxygen of the sample. Under anaerobic conditions, nitrate nitrogen is subject to denitrification and loss to the atmosphere as nitrogen gas.

To substantiate the bacterial action hypothesis, four samples were obtained at the one-half point and tail of the wastewater sump. A fixed composite sample was prepared for each location from each sample. Immediate analysis of the grab samples was determined for nitrate. Four hours after obtaining the first sample, nitrate determinations were made on each fixed composite sample and an unfixed spray composite sample. Table 21 give the result of these determinations.

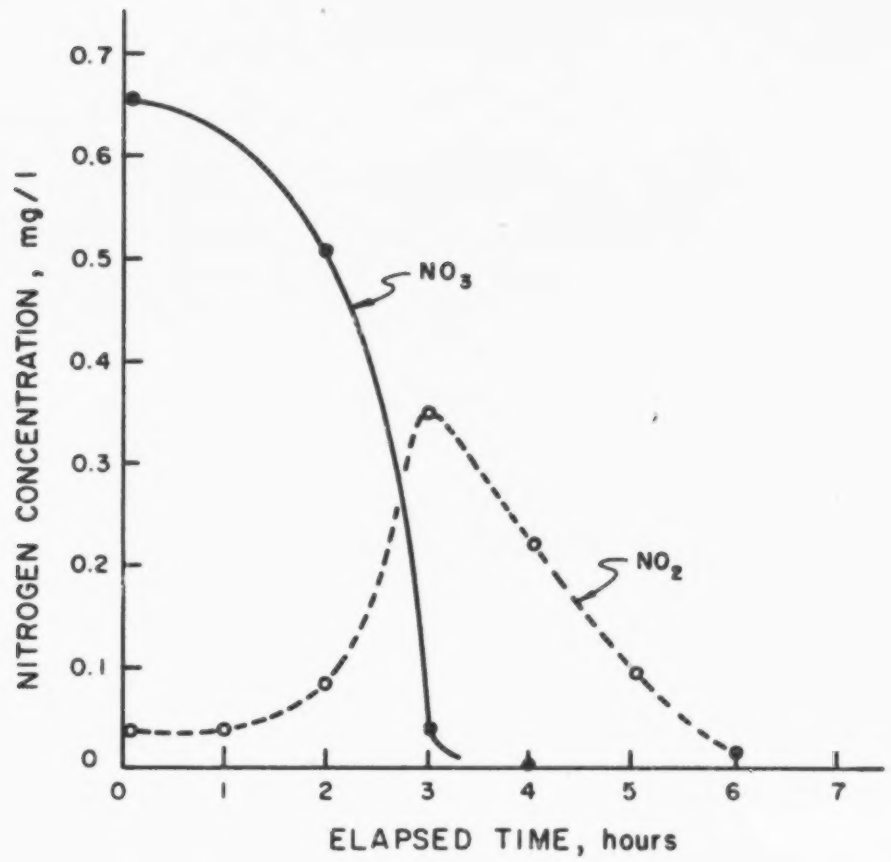

FIGURE 7— CHANGES OF NITRATE AND NITRITE CONCENTRATIONS WITH TIME IN UNFIXED WASTEWATER SAMPLES

TABLE 21

NITRATE IN FIXED AND UNFIXED WASTEWATER SAMPLES

Sample	Nitrate, mg/l N
1/2 Point Grab, unfixed (avg)	1.29
1/2 Point Composite, fixed	1.36
Tail Grab, unfixed (avg)	1.18
Tail Composite, fixed	1.28
Field Spray Composite, unfixed	<.05

The results of this investigation prompted the decision to obtain two samples at the field spray sampling locations. One was fixed with concentrated sulfuric acid and the other was unfixed. Those results are shown in Table 4 (Chap. 3) of this report.

Recovery of Treatment Efficiency by Resting

Previous experience with the treatment system had shown that a rest of several weeks would allow a watershed to recover its ability to treat the wastewater. The results of laboratory studies have indicated that a rest of two to three weeks should allow recovery.[3] Experimental watersheds were shut down four times during the one-year study because their treatment efficiencies had declined markedly. The effect of the rest period on the treatment efficiency of the watersheds is summarized in Table 22.

[3]Warren A. Schwartz, Thomas W. Bendixen, Richard E. Thomas, "Project Report of Pilot Studies on the Use of Soils as Waste Treatment Media," USDI, FWPCA, Cincinnati, Ohio, 1967. Unpublished data.

TABLE 22

RECOVERY OF TREATMENT EFFICIENCY BY RESTING A WATERSHED

Watershed	Rest period days	Percent concentration reduction for total nitrogen and COD					
		before rest		first week after rest		fourth week after rest	
		N	COD	N	COD	N	COD
B-11	56	50	54	64	86	83	88
B-11	11	3	61	10	77	92	93
G-11	11	65	86	87	88	87	88
B-11	12	0	54	39	88	87	90

Note: Abbreviations of chemical parameters are explained in Appendix I.

These data showed that a rest of 11 or 12 days was as effective as a rest of 56 days in restoring the treatment efficiency of a watershed. The data also showed that it takes several weeks after wastewater applications are restarted to fully regain the treatment efficiency. The treatment efficiencies for the fourth week after restarting wastewater applications were as good as the average concentration reductions for the system which were 84 percent for total nitrogen and 92 percent for COD. These results substantiated the previous laboratory work on the effect of rest periods and indicated that a rest period of two weeks is usually sufficient to restore full treatment capacity to this system.

Nitrogen Transformations Due to Extended Drying of a Watershed

It was shown in Chapter V that the nitrogen concentration in the field effluent averaged 16 percent of that in the wastewater and that the nitrogen in the field effluent is in the form of organic nitrogen

under normal operating conditions. The 56-acre watershed draining to the farm effluent sampling station was shut down for 4 weeks in July and August. The percent nitrogen removal and the chemical form of the nitrogen in the field effluent following the resumption of wastewater applications are presented in Figure 8. These results provide qualitative support of the hypothesis that microbial metabolism plays an important role in the nitrogen removal process. The lag time for the treatment system to regain full nitrogen removal capacity is characteristic of processes depending on microbial activities. The rise in the fraction of the nitrogen recovered as nitrate was indicative that the environment was predominantly aerobic through the tenth day after restarting wastewater applications. The subsequent fall in the nitrate concentration and the continued drop in the total nitrogen concentration suggested that denitrification processes became dominant between 10 and 17 days. It would appear that the conditions under which this soil treatment system was operated provided an environment which supported denitrification as the final metabolic process acting upon the nitrogeneous compounds in the wastewater. The gaseous end products of this process could account for the apparent loss of about 80 percent of the total nitrogen applied to the soil treatment system.

Analysis of Rainfall Runoff

A set of runoff samples from rainfall only was obtained on one occasion during the 12-month study. The analyses of these samples and the subsequent wastewater-spray runoff for selected parameters are presented in Table 23. The averages for July 10, 1968, are included as an indication of the quality for a comparative period with no rainfall. This single comparison was for a rainfall of 0.5 inches followed by a wastewater spray of 0.9 inches. The results showed that a rainfall incident of this amount produced runoff which is similar in composition to the runoff from the subsequent wastewater spray. There was an indication that both the rainfall runoff and subsequent wastewater-spray runoff were diluted relative to the runoff for the comparable no-rainfall period.

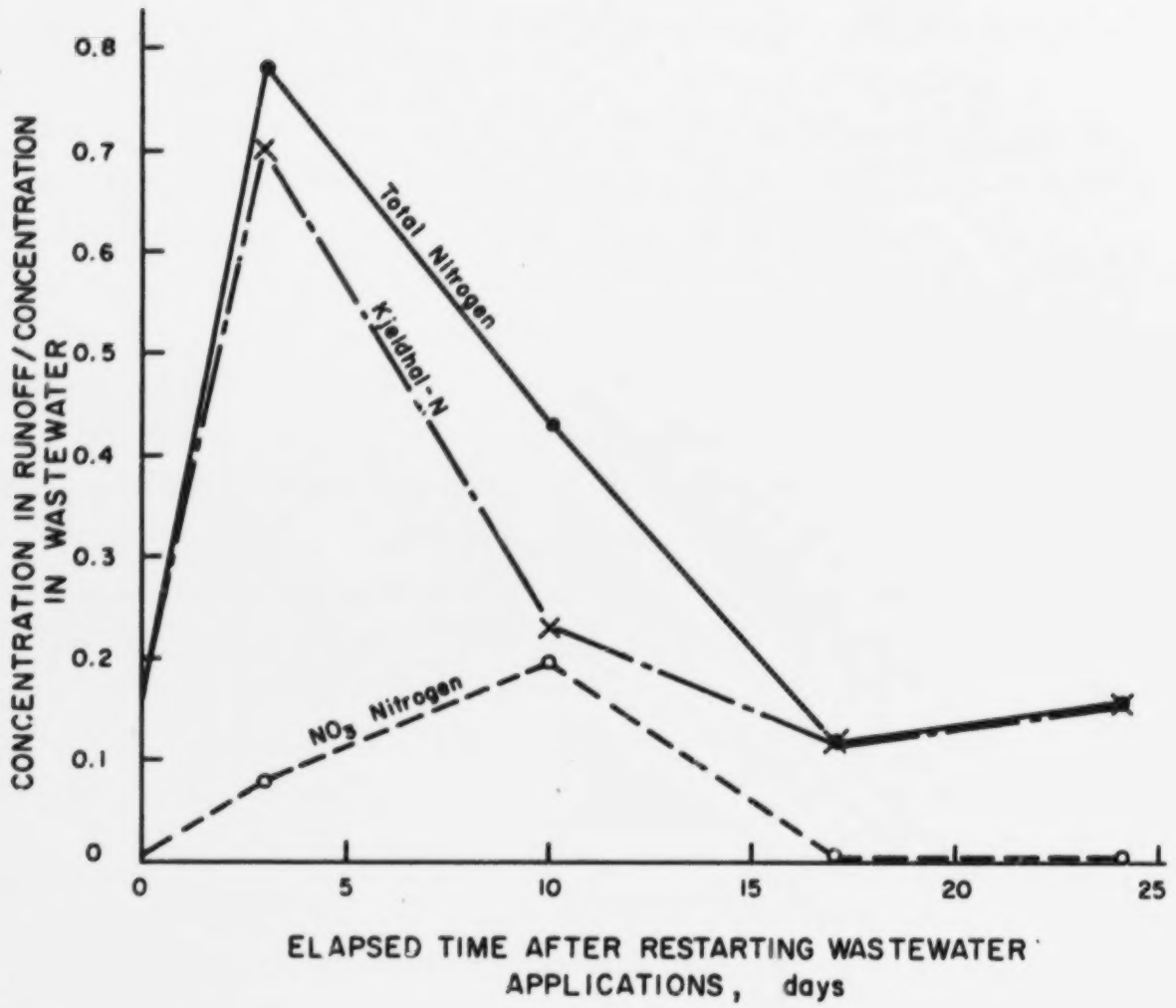

FIGURE 8—EFFECT OF EXTENDED DRYING ON NITROGEN TRANSFORMATIONS AND PERCENT REMOVAL

TABLE 23

MEAN CONCENTRATION OF RAINFALL RUNOFF AND SUBSEQUENT WASTEWATER-SPRAY RUNOFF FROM THE EXPERIMENTAL WATERSHEDS

Runoff Source	Concentration in mg/liter					
	BOD	COD	TSS	T-N	T-P	Cl
Rainfall	9	47	14	3.4	5.4	69
Wastewater spray	7	32	14	3.5	6.9	46
Four watersheds 7/10/68	8	100	18	4.6	4.6	81

Note: Abbreviations of chemical parameters are explained in Appendix I.

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APPENDIX I

Description of Chemical Parameters

pH--The pH value denotes the degree of alkalinity or acidity of a sample. The neutral position on a pH scale is 7.0. Any value less than 7.0 is of an acid nature, while that above 7.0 is alkaline. The pH of most natural waters ranges from 6.0 to 8.0.

DISSOLVED OXYGEN--Dissolved oxygen is the quantity of free or uncombined oxygen in water. The self-purification of streams is dependent on the quantity of oxygen incorporated within the water.

CONDUCTIVITY (Cond.)--Electrical conductivity is a quick and reliable measurement of electrolyte concentration in a water sample. The conductivity measurement can be related to dissolved solids concentration and is almost directly proportional to the ionic concentration of the total electrolytes.

SUSPENDED SOLIDS

Total Suspended Solids (TSS)--Total suspended solids is a determination by weight/volume of the suspended material in water too large to pass through a fine-porosity, glass fibre filter.

Volatile Suspended Solids (VSS)--The volatile suspended solids is the loss of weight when the total suspended solids has been ignited at 600°C. This is considered to be principally organic matter. The difference between total suspended and volatile suspended solids is the fixed suspended solids which are primarily the mineral constituents of the water sample.

TOTAL PHOSPHORUS (T-P)--Phosphorus is a potential nutrient for plant growth. A beneficial compound in water except when found in abundant excess. The total phosphorus determination is performed by the persulfate digestion procedure which breaks down all forms of phosphorus to the ortho form.

CHLORIDE (Cl)--Chloride is found in all natural waters in a wide range of concentrations. The effect of chlorides on soils and plants and the concentration which various plants can withstand are replete in literature. The USPHS suggests the maximum concentrations of chlorides for drinking water not to exceed 250 mg/l Cl^-.

ALKALINITY--Alkalinity concentrations in water are primarily due to the bicarbonate, carbonate, and hydroxide ions. The alkalinity represents the buffering capacity of the water. Increased concentrations of alkalinity over the carriage water are due to industrial wastes. The relationships between total (T-Alk) and phenolpthalein (P-Alk) alkalinity are located below:

Condition	Type of Alkalinity
P=T	Hydroxide
P=1/2 T	Carbonate
P=0	Bicarbonate
P>1/2 T	Hydroxide, Carbonate
P<1/2 T	Carbonate, Bicarbonate

NITROGEN

Organic Nitrogen (Org. N)--Represents a measure of the nitrogen in the form of protein or intermediate decomposition products. An increase of organic nitrogen content indicates an increased pollution load. The calculation of organic nitrogen is made by subtracting the ammonia nitrogen from the total Kjeldahl nitrogen (Kjel. N).

Ammonia Nitrogen (NH_3-N)--This form of nitrogen represents the microbiological decay of plant and animal proteins. When ammonia nitrogen is found in waters, it is indicative of incomplete treatment.

Nitrite Nitrogen (NO_2-N)--Is an intermediate stage in the decomposition of organic nitrogen to the nitrate form. The value of this test is to determine whether the applied treatment is sufficient.

Nitrate Nitrogen (NO_3-N)--Is the final decomposition product of the organic nitrogen compounds. Determination of this parameter indicates the degree of waste treatment.

Cumulative Total Nitrogen (T-N)--Is the arithmetic sum of ammonia nitrogen, nitrate, nitrite, and organic nitrogen. This differs from the total Kjeldahl nitrogen in that nitrates and nitrites are included.

CHEMICAL OXYGEN DEMAND (COD)--Is the amount of oxygen consumed in the oxidation of organic and oxidizable inorganic matter in wastewater. The test is used as an indication of the organic strength of the wastewater.

TOTAL ORGANIC CARBON (TOC)--This parameter is still in the developmental stage, but the results obtained appear promising as a means to determine the organic quantity in wastewater. Relationship values between the COD and TOC are very encouraging. The value of this procedure is that a sample can be analyzed in 5 minutes.

BIOCHEMICAL OXYGEN DEMAND (BOD)--This determination is a measure of the oxygen required to oxidize the organic material in a sample of wastewater by natural biological processes under standard conditions. This test is presently universally accepted as the yardstick of pollution and is utilized as a means for the degree of treatment in a waste treatment process.

APPENDIX II

CHEMICAL DATA FORM FOR SURFACE WATER SAMPLES

Date September 10, 1968

Spray Period 0700-1500

Sample	pH	Cond. µmhos /cm	Concentration, mg/liter												
			TSS	VSS	T-P	Cl	P-Alk	T-Alk	NO_3 N	NO_2 N	Kjel. N	T-N	COD	TOC	BOD
Spray	5.5	400	192	176	4.1	45	0	20	.09	<.05	15.7	15.8	751	228	485
G-4 Runoff	7.6	440	4	2	4.0	36	0	144	.11	<.05	1.8	1.9	62	25	8.9
G-11 Runoff	7.8	400	5	4	3.7	37	0	96	.07	<.05	2.3	2.4	77	29	11
B-11 Runoff	7.6	375	13	9	6.0	32	0	106	.10	<.05	2.6	2.7	33	25	10
Y-1 Runoff	7.8	450	8	4	4.1	36	0	151	<.05	<.05	1.9	1.9	62	23	3.5
GWY Field Eff.	7.2	390	6	3	3.7	31	0	105	.08	<.05	1.9	2.0	62	27	2.5

Note: Abbreviations of chemical parameters are explained in Appendix I.

APPENDIX III

CHEMICAL DATA FORM FOR SOIL WATER SAMPLES

Date April 24, 1968

Spray Period 0100-0700

Sample Area	pH	Cond. µmhos/cm	Concentration, mg/liter													
			P-Alk	MO T-Alk	NO_3N	NO_2N	OrgN	NH_3N	T-N	T-P	SO_4	Ca	Mg	Na	K	Cl
G-4	6.7	1300	0.0	60.0	.07	<.05	2.9	0.2	3.2	0.3	570	88	20	257	1.4	190
G-11	6.0	240	0.0	30.0	<.02	<.05	<.1	<0.1	---	1.5	25	24	2	30	0.6	69
B-11	6.0	440	0.0	26.0	.12	<.05	0.4	0.1	.6	0.4	60	19	3	110	1.0	63
Y-1	6.6	1350	0.0	50.0	.12	<.05	0.7	1.1	1.9	0.4	275	94	14	225	1.7	322

Note: Abbreviations of chemical parameters are explained in Appendix I.

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SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

5 Organization: ~~U. S. Department of the Interior, Federal Water Pollution Control Administration, South Central Region,~~ Robert S. Kerr Water Research Center, ~~Water Quality Control Research Program,~~ Ada, Okla~~homa~~

6 Title: NUTRIENT REMOVAL FROM CANNERY WASTES BY SPRAY IRRIGATION OF GRASSLAND

10 Author(s)
Law, James P., Jr.
Thomas, R. E.
Myers, Leon H.

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25 Identifiers (Starred First)
*Grassland irrigation, *Soil treatment system, Spray-runoff, Cannery waste water, Nutrient removal.

27 Abstract: The Campbell Soup Company plant at Paris, Texas, treats wastewater from the processing operations by spraying onto grassland. Vegetable solids and grease residues are separated and recovered. A comprehensive 12-month study was conducted to determine treatment efficiencies of the spray-runoff treatment system. A total of 133 inches of wastewater was applied to four experimental areas during the study period. Hydrological measurements, chemical removal efficiencies, and changes in soil properties were evaluated in relation to years of wastewater application, soil type, and spray schedule.

Hydrological measurements accounted for 93 percent of the total liquid applied and showed that evaporative losses accounted for 18 percent of the total liquid applied; runoff accounted for 61 percent. During periods of heavy rainfall, runoff increased to a maximum of 80 percent of the total applied liquid.

The results showed that the system achieved mass removals of 92 to 99 percent of the volatile solids and oxygen-demanding substances, 86 to 93 percent of total nitrogen, and 50 to 65 percent of phosphorus. Soil textural class and system age had very little effect on treatment efficiencies.

Evaluation of surface and subsoil samples and soil water at the 3-foot depth indicated an increase in salinity with age, but nitrogen and phosphorus remained low. Much of the phosphorus removed from the wastewater was found in the surface soil layer.

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